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THE UTILIZATION OF THE BEHAVIORAL  
SCIENCES IN LONG RANGE FORECASTING  
AND POLICY PLANNING

Stuart J. Thorson

Ohio State University Research Foundation

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provide a basis for defining and testing the relations between these indicators. In a future phase of the Project, mathematical control theory and (subjective) dynamic programming (augmented with user stated objectives in each country) will be applied to identify "best" mixes of U.S. policy toward each country.

As a substantive target, U.S. relations with Saudi Arabia, Iran, Iraq, Libya, and Algeria are being studied. Thus far the emphasis has been upon Iran and Saudi Arabia. Each country simulation is divided roughly into four modules - an agriculture module, an oil module, a human resources and national accounts module, and a government or "decision-making" module (this structure is shown schematically in Figure I.1). In order that these simulations have maximal impact upon the policy planning community and in order to take advantage of the knowledge of planners, the simulations are being developed in close interaction with policy planners in both the Defense and State Departments.

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THE UTILIZATION OF THE BEHAVIORAL SCIENCES  
IN LONG RANGE FORECASTING AND POLICY PLANNING

Semi-Annual Technical Report No. 4

S. J. Thorson

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## I. INTRODUCTION

1.1: Summary of Technical Work to Date. The goals of the project have been the development of forecasting techniques to the point where the impact of alternative U.S. foreign policies toward specific countries can be assessed in alternative strategic environments. As a way of achieving this objective, the Project is developing computer simulations of several Middle-East oil producing nations. In doing this, assumptions about the relations between U.S. policies and policy actions and country and region specific indicators of stability are being expressed in a mathematical language. Results from current ARPA supported basic research efforts are being used to provide a basis for defining and testing the relations between these indicators. In a future phase of the Project, mathematical control theory and (subjective) dynamic programming (augmented with user stated objectives in each country) will be applied to identify "best" mixes of U.S. policy toward each country.

As a substantive target, U.S. relations with Saudi Arabia, Iran, Iraq, Libya, and Algeria are being studied. Thus far the emphasis has been upon Iran and Saudi Arabia. Each country simulation is divided roughly into four modules - an agriculture module, an oil module, a human resources and national accounts module, and a government or "decision-making" module (this structure is shown schematically in Figure I.1). In order that these simulations have maximal impact upon the policy planning community and in order to take advantage of the knowledge of planners, the simulations are being developed in close interaction with policy planners in both the Defense and State Departments.

During the first phase of the contract, the following tasks have been completed.

- Developed and completed preliminary testing of the oil, agriculture, and human resources modules. These modules are described in detail in PTP Working Papers 15-16, and 23.
- The oil, agriculture, human resources, and preliminary control modules are coded and running interactively on the O.S.U. IBM 370/165.
- To assist in the development and testing of the simulations, working relations have been continued with Maj. General W.Y. Smith, Director, Policy Plans and NSC Affairs, OSD/ISA; Tom McAndrews, Director, NEA/INR; Hal Ford OPR/CIA; Dr. Robert Jones, OCI/CIA; W. Hutchinson, NTO (Saudi Arabia).
- Developed preliminary versions of country-specific decision modules. These modules are designed to reflect actual bureaucratic structures within the relevant governments. Some of the theoretical issues underlying these modules are discussed in PTP Working Papers 1, 3, 4, 6, 8, 9, 10, 12, 13, 14, 18, 20, 21, 22, 26, 27, 28, and 29.

- Developed software and displays to run entire simulation interactively. This involved the writing of a Terminal Monitor Program which, among other things, allows the user to change the structure of the program as well as simply changing variable values. This is of great use in obtaining immediate feedback from users during demonstrations.
- Preliminary identification of major policy objectives (domestic and foreign) of Iran, Saudi Arabia, Iraq, Libya and Algeria. These serve as "data" for the decision modules and were generated through analysis of public documents and budgetary allocations and expenditures. The procedures and results are described in PTP Working Paper 14.
- Developed event based simulation modules to demonstrate policy implications of that data source. These are described in PTP Working Papers 1, 3, 4, 5, 12, and 20.
- Developed routines for using interactive computer simulations to elicit goals and strategies from policy analysts. These are described in PTP Working Papers 2, 11, 24, and 25.
- Identified roles of forecasting in policy planning. These are described in PTP Working Papers 2, 11, 24, and 25.
- Begun programming of the Decision Module for Saudi Arabia.

As in previous Semi-Annual Reports, Sections II-VI will summarize technical accomplishments during the past six months. Detailed statements of progress during the past six months are found in Technical Reports 26-31 (attached). These reports are referenced in the next sections.

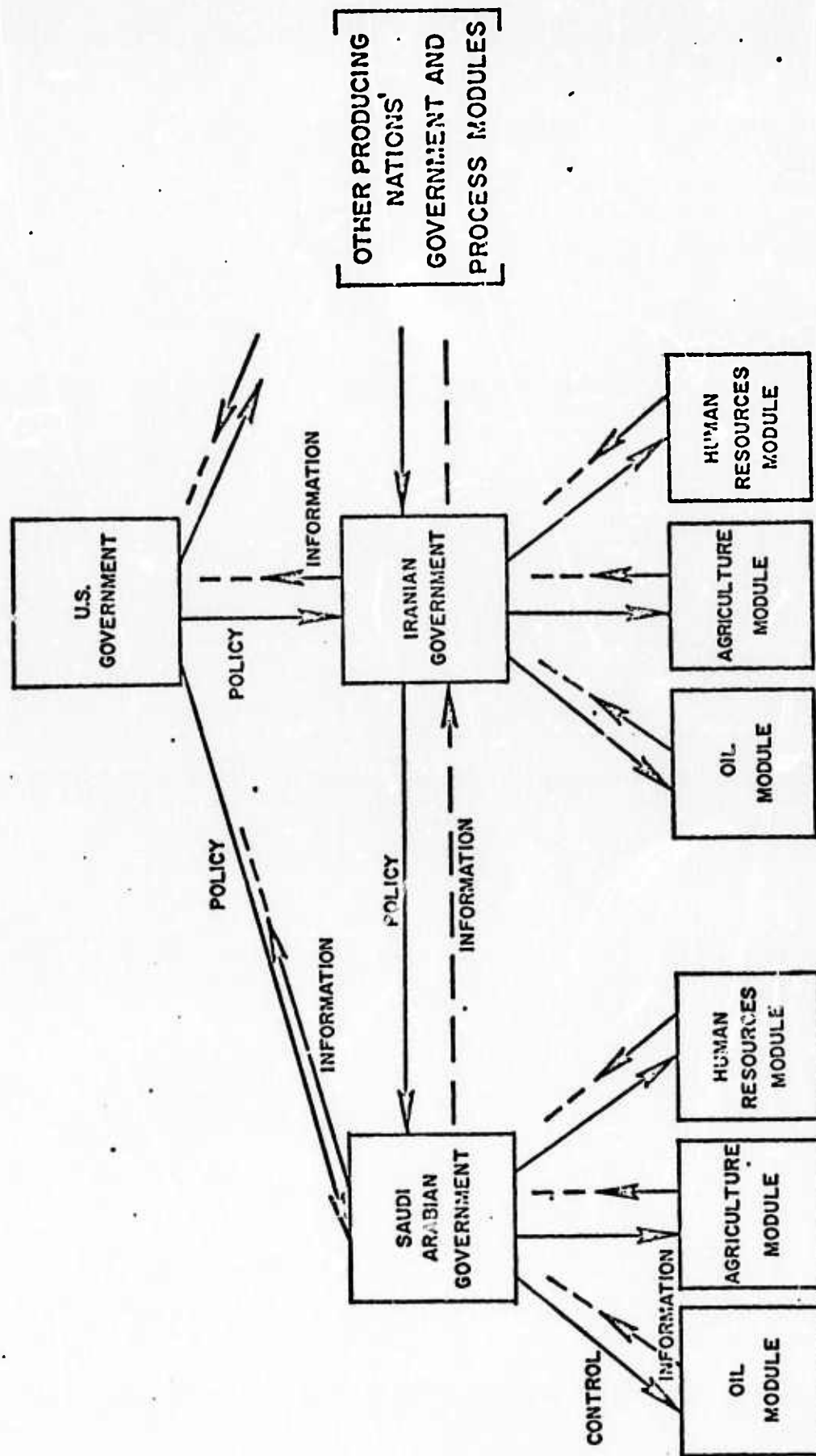


Figure 1-1 Overall Structure of the Simulation

## II. THE DECISION MODULE

Since the last report, a major portion of research time has gone into developing a decision module for Saudi Arabia. Project reports 26, 27, 28, and 30 detail progress in this area. In summary, work has proceeded in four areas:

- 1) An investigation and exploration of the formal properties of production systems and their utility in modelling multi-goal governments;
  - 2) An inquiry into the nature of goals, and the characteristics of goal seeking;
  - 3) The discussion of issues involved in the specification of the decision module as a language processor;
  - 4) The first pass at the specification of a production system to control the agriculture sector module.
- (1) Since the production system notion used for the specification of the decision module is formally equivalent to a Markov normal algorithm, and theorems exist linking production systems with the more general theory of automata, work is underway to assess the what (if any) aspects of that general body of mathematical theory is relevant to our efforts.
- (2) Since goals and goal seeking are central to the effort of the specification of the decision module, work is continuing on these topics. One area of investigation involves the correspondence between a goal seeking system formulated as a production system, and the more general formulation of goal seeking found in Mesarovic's work in mathematical systems theory. The second area of investigation concerns the nature of goals, goal seeking systems, and the predication of goals to systems with specific relation to published statements from the Saudi Government.
- (3) Since the decision module will be built as a language processor, investigation is currently underway as to the techniques and issues involved in building a production system with the capability to "perceive" and make inferences based upon sentences describing states of the environment (e.g., the oil, agriculture, and human resources modules). It is hoped this approach will permit the use of events data in the testing of the simulation.
- (4) A working version of a production system with the capability to control the agriculture module has been written. The production system is programmed in the list processing language, SNOBOL. With the recent completion of a working version of the agriculture module, work in this area will be focused on the technical problems of interfacing the a SNOBOL program with a PL/1 program, as well as the specification of control modules for human resources and the oil modules. The PTP Terminal Monitor Program (see last semi-annual report, section 4.2) will be used in the interface.

FIGURE II-1

## Simple Flowchart of Computer Program

Transfer Control  
From Decision Module

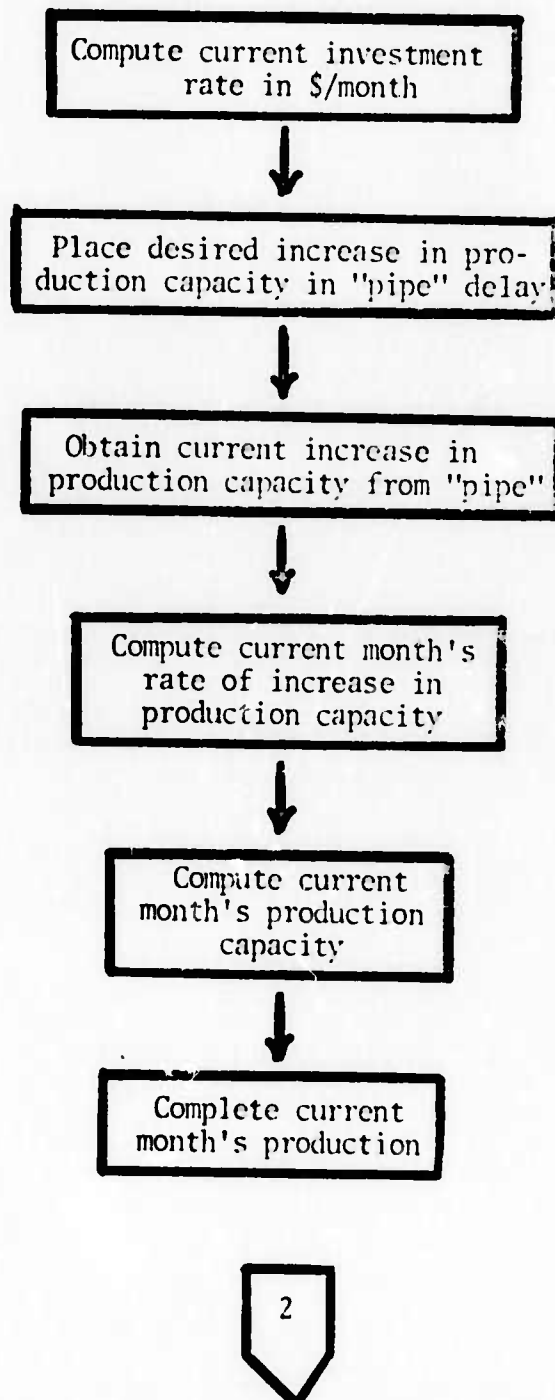


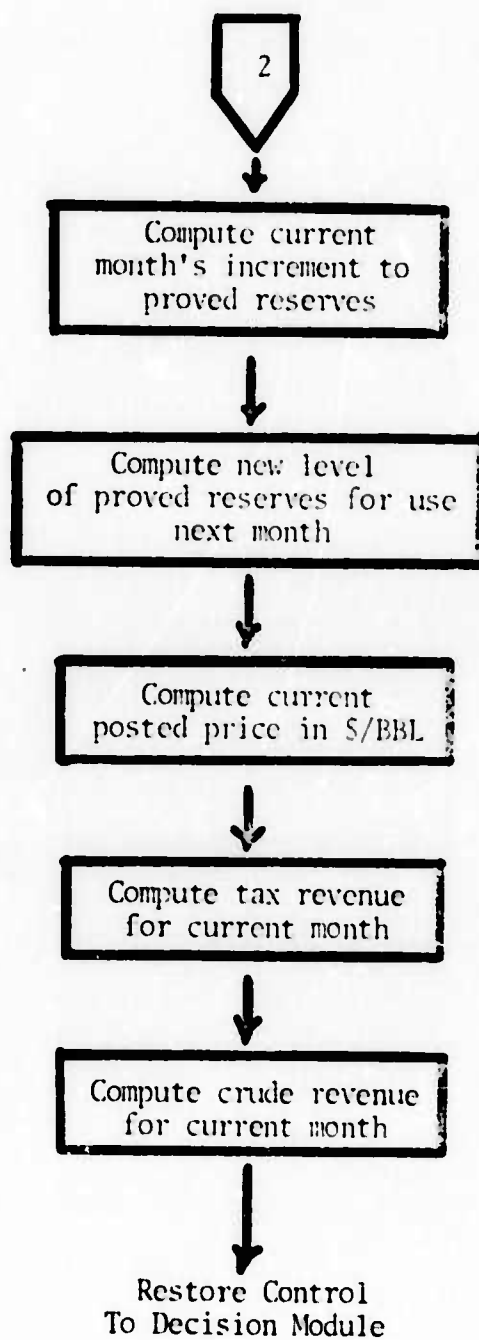
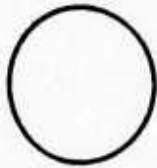
FIGURE II-1 (cont.)

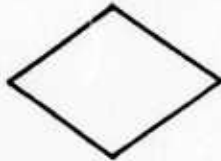


FIGURE II-2a

Legend for symbols used in Figure II-2b:



Process information variable



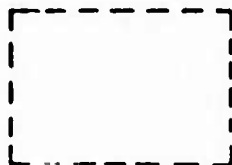
Control information from control stratum



Exogenous information provided by user

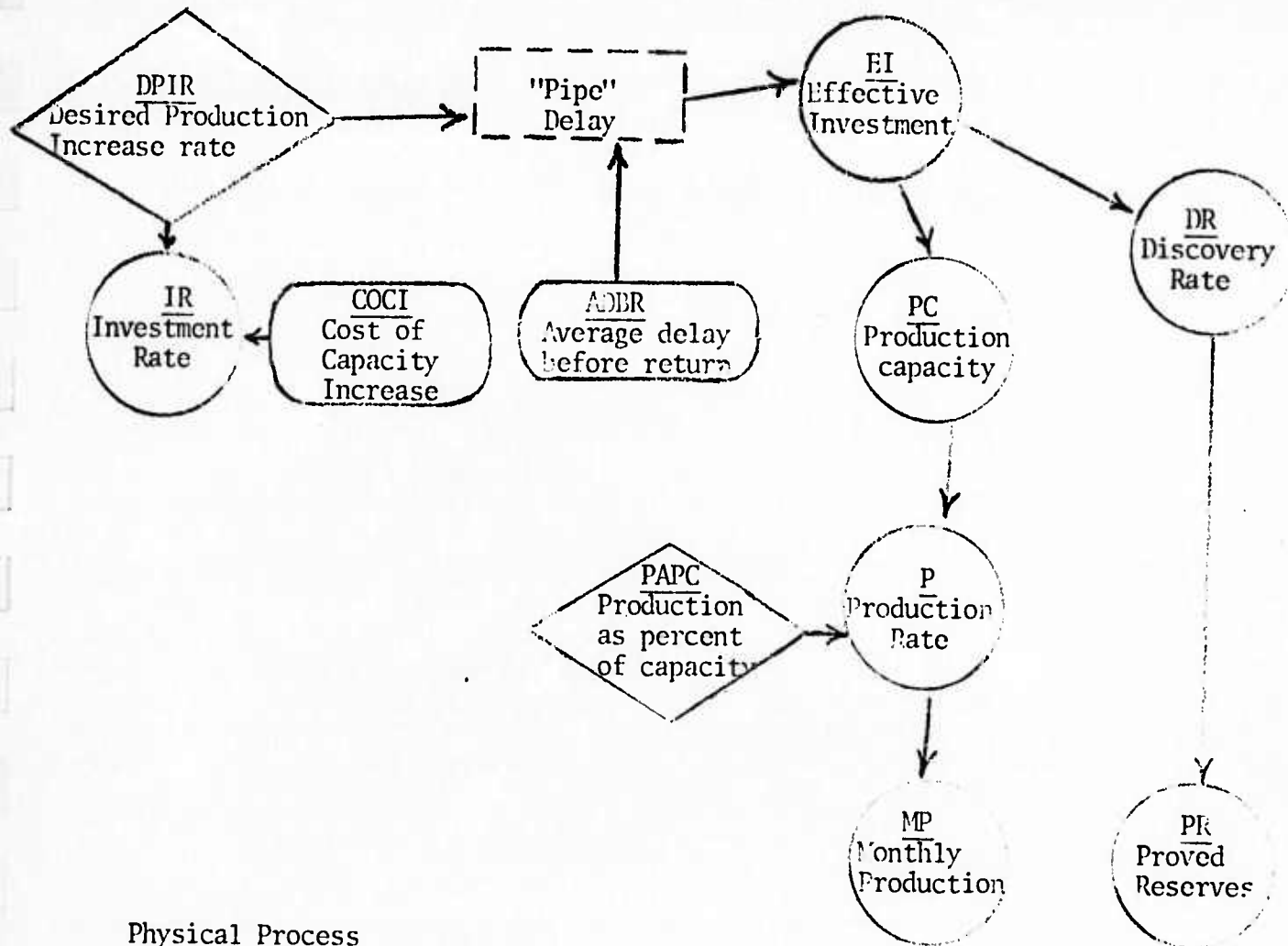


Indicates influence of one variable upon another

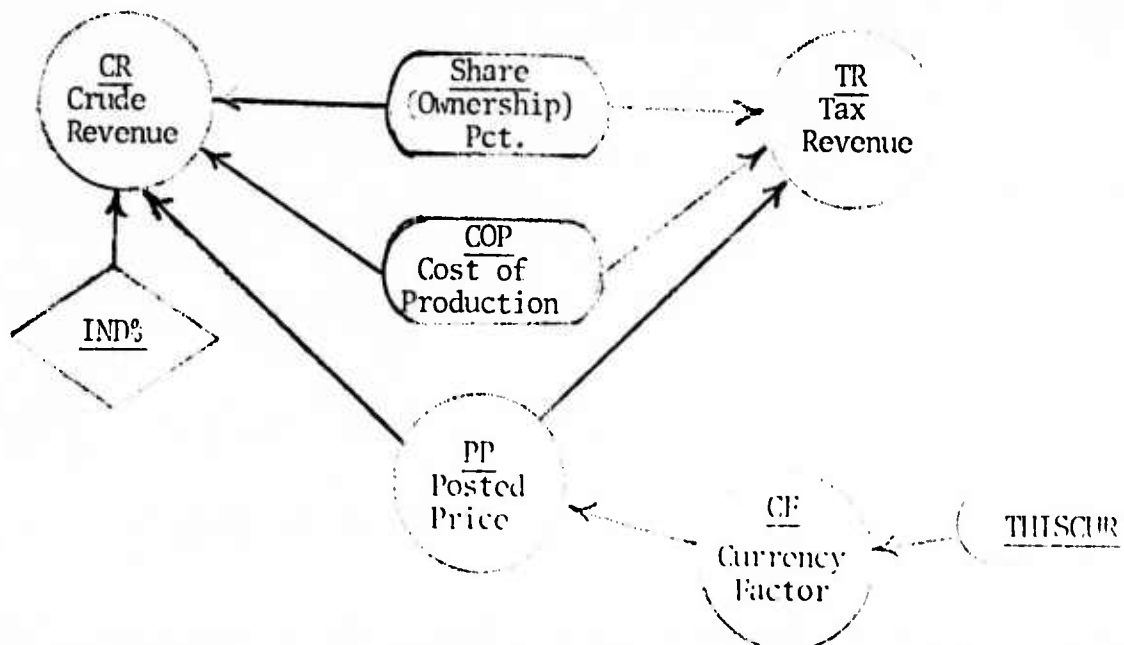


Specifies additional detail concerning a particular influence mechanism

FIGURE II-2b  
Conceptual Flowchart of Module



Contractual Arrangements



### III. OIL MODULE

The Project presently has available on a stand-alone basis, a running simulation module for the oil industry in Saudi Arabia. It consists of three "stages", each of which represents a specific time period.

The first "stage" is used for the years 1963-1972, and although it makes no attempt to model explicit country-company relationships, it provides values for Saudi Arabia's income from oil revenues for those years. It determines the monthly revenue for any given month of that period by taking one-twelfth of Saudi Arabia's revenue for the appropriate year. The annual revenue figures are taken directly from Table 95 of the OPEC Statistical Bulletin for 1972. The primary purpose of the first stage is to provide revenue data which permit testing other simulation modules over the 1963-1972 time period.

The second stage models country-company relationships for the year 1973. Revenues resulting from the sales of independent and sellback crude are kept distinct from tax and royalty revenues, and the Saudi government's growing control over production capacity, production level, and prices is included in the stage.

The third stage simulates the period beginning January 1974. In this stage, the producing country government sets production levels and prices unilaterally, disregards entirely the Teheran, Geneva I and Geneva II agreements, and determines its own share of participation. It is anticipated that this third stage is flexible enough to permit simulation of various alternate futures through simple changes in its parameters. This third stage is a recent modification, and represents changes made to reflect events of the six to nine months.

Research Report Number 23 provides an interim user's manual for the Oil Module in its present stand-alone form, and includes examples of needed user input and suggestions for simulation of recent events. Figures II-1 and II-2 illustrate the logical structure of this module.

#### IV. AGRICULTURE MODULE

Although oil is the dominant factor in the economy of Saudi Arabia, focusing solely upon the oil sector would omit much of interest and importance to the Saudi policy-maker. For example, the agricultural sector is the principal source of employment, with more than half the population deriving its livelihood from agriculture. In addition, after oil production agriculture makes the largest single contribution to the national accounts. However, the agricultural sector in Saudi Arabia (and other countries) suffers from a relatively low level of productivity, and a considerable development effort is needed in order to reduce reliance on imported food.

It is in the context of such a development effort that we have developed a simulation model of the agricultural sector of Saudi Arabia. Its purposes are to (1) identify and trace the various information and material flows in the agricultural production process which influence the decision makers' choices of developmental policies and programs, and (2) project the consequences that these choices might have.

The present model is a revised version of the model presented in PTP Paper No. 16. It incorporates changes which both correct errors in the earlier version and tailor the model more specifically for Saudi Arabia. A discussion of the assumptions underlying the revised model's structure is presented (in Section F) of PTP working paper 32. Sample output from the model is presented in an Appendix, along with initial values and parameters used in producing it.

## V. DATA

5.1: Data holdings have not changed since the previous Semi-Annual Report.

## VI. PERSONNEL

### 6.1: Principal Investigators

Professor Thorson has been primarily involved in the development of the human resources, agriculture, and decision modules. He presented project supported papers to the meetings of the American Political Science Association, the Mid-Atlantic General Systems Society and to the Society for General Systems Research. In addition he has visited the University of Minnesota to discuss the project with a group there which is doing related research under an NSF grant.

Dr. Phillips has continued to spend considerable time developing working relations with policy-makers so that these people can be used as one source of external validation for the decision models. In addition, he has begun preliminary validation efforts with respect to oil and agriculture.

## VII. HUMAN RESOURCES MODULE

The human resources module provides information to the decision module for Saudi Arabia in the form of numerical descriptions of the Saudi educational and manpower sectors. The precise nature of this module is described in PTP Working Paper No. 31.

The human resources module of Saudi Arabia is constructed as a linear flow process. Using basic data on population, education, and manpower categories, a vector description of Saudi human resources is constructed. So that this vector can be inspected at regular, yearly intervals, a transition table is necessary. Estimation of transition probabilities has occupied considerable time and effort during the past six months. Details of this procedure as well as the choice of vector categories are in PTP Report 31.

## VIII. PUBLICATIONS AND WORKING PAPERS

8.1: Publications (Numbers 13-16 additions this period)

- No. 1. Phillips, W.R. and T. Lorimor, "The Effect of Crisis Upon the Stability of the International System", Multivariate Behavioral Research, Vol. 9, October 1974.
- No. 2. Phillips, W.R. and R.C. Crain, "Dynamic Foreign Policy Interactions: Reciprocity and Uncertainty in Foreign Policy", The Sage International Yearbook of Foreign Policy Studies, Vol. II, 1974.
- No. 3. Phillips, W.R., "Where Have All the Theories Gone?" World Politics, January 1974 (also an O.S.U. mimeo 1972).
- No. 4. Phillips, W.R., "Theoretical Approaches in the Events Data Movement", International Interaction, Vol. II, (forthcoming).
- No. 5. Phillips, W.R., "Forecasting for Planning", Knowledge and Diplomacy: The Interaction of Research and Foreign Policy, (forthcoming).
- No. 6. Thorson, S. and J. Stever, "Classes of Models for Selected Axiomatic Theories of Choice", Journal of Mathematical Psychology, Vol. II, No. 1 February 1974.
- No. 7. Thorson, S., "National Political Adaptation in a World Environment", Comparing Foreign Policies, (Sage, 1974).
- No. 8. Thorson, S., "Adaptation and Foreign Policy Theory", The Sage International Yearbook of Foreign Policy Studies, Vol. II, (Sage, 1975).
- No. 9. Wendell, R. and S. Thorson, "Some Generalizations of Social Decisions Under Majority Rule", Econometrica, (forthcoming).
- No. 10. Thorson, S., "Problems in Constructing Descriptive, Policy and Design Theories of Foreign Policy Behavior", In Search of Global Patterns, (Free Press, forthcoming).
- No. 11. Phillips, W.R. and Thorson, S., "Simulation for Policy Planning", in the Fifth Annual Pittsburgh Conference Proceedings on Modeling and Simulation, (1974).
- No. 12. Thorson, S., "The Inter-Nation Simulation Project: A Methodological Appraisal" in Quantitative International Politics: An Appraisal (Praeger Publication, forthcoming).
- No. 13. Thorson, S., "Modeling Control Structures for Complex Social Systems", Interdisciplinary Aspects of General Systems Theory, (1975).
- No. 14. Phillips, W.R., "Some Comments on the State of General Systems Theory", Interdisciplinary Aspects of General Systems Theory, (1975).
- No. 15. Anderson, P.A., "Role of Complete Processing Models in Theories of Inter-Nation Behavior", to appear in World Studies.
- No. 16. Thorson, S. "Modelling for Policy Planning", in G. Hilliker (Ed.) Knowledge and Diplomacy: The Interaction of Research and Foreign Policy, (O.S.U. Press, forthcoming).

## VIII. PUBLICATIONS AND WORKING PAPERS (cont.)

8.2: Working Papers (Numbers 26-32 new additions this period)

- No. 1. Phillips, W.R., "Theoretical Underpinnings of the Event Data Movement"
- No. 2. Phillips, W.R., "Forecasting for Planning"
- No. 3. Phillips, W.R., "Dynamic Foreign Policy Interactions"
- No. 4. Phillips, W.R. and P. Callahan, "Dynamic Foreign Policy Interactions: Some Implications for a Non-Dyadic World"
- No. 5. Phillips, W.R. and M. Hainlain, "Major Power Conflict Exchanges in the Sixties: A Triadic Analysis of the U.S., Soviet, and Chinese Sub-System From a Comparative Foreign Policy View"
- No. 6. Thorson, S. and R.E. Wendell, "Location Theory and the Social Sciences"
- No. 7. Thorson, S. and J. Stever, "Classes of Models for Selected Axiomatic Theories of Choice"
- No. 8. Thorson, S. and R.E. Wendell, "Some Generalizations of Social Decisions Under Majority Rule"
- No. 9. Thorson, S. and R.E. Wendell, "A Mathematical Study of Decisions in a Dictatorship"
- No. 10. Thorson, S. "National Political Adaptation in a World Environment"
- No. 11. Thorson, S. "Comments on Some Problems in Constructing Descriptive, Policy and Design Theories of Foreign Policy"
- No. 12. Phillips, W.R., Patrick T. Callahan and Robert C. Crain, "Simulated Foreign Policy Exchanges, The Rationale Underlying a Theory of Foreign Policy Interaction"
- No. 13. Anderson, Paul, "The Decision Module"
- No. 14. Callahan, P.T., "An Analysis of the Goals of Five Oil Producing Nations"
- No. 15. Crain, R.C., "Oil Module"
- No. 16. Hainline, M.K., "Agricultural Sector Module: A Preliminary Sketch"
- No. 17. Hermann, C.F., W.R. Phillips, and S.J. Thorson "Theories and Forecasting in International Relations: The Role of Validation Efforts"
- No. 18. Thorson, S.J., "Adaptation and Foreign Policy Theory"
- No. 19. Gonzales, C.C., "Military Security Assistance to the Persian Gulf States"

- No. 20. Anderson, P.A., "A Discussion of Issues in Need of Resolution: Toward a Specification of the Decision Module"
- No. 21. Anderson, P.A. and Miller, P.L., "Why War: A Mathematical Systems Approach"
- No. 22. Buss, T.F., "Dimensionality and Spatial Modelling: A Critical Assessment"
- No. 23. Crain, R.C., "Interim User's Guide for the Oil Module"
- No. 24. Phillips, W.R. and Thorson, S.J., "Simulation for Policy Planning"
- No. 25. Thorson, S.J., "The Inter-Nation Simulation Project: A Methodological Appraisal"
- No. 26. Anderson, P.A., "Further Discussion of Issues in Need of Resolution: Notion of a Sentence Writer"
- No. 27. Thorson, S.J., "Modeling Control Structures for Complex Social Systems"
- No. 28. Anderson, P.A., "The Role of Complete Processing Models in Theories of Inter-Nation Behavior"
- No. 29. Phillips, W.R., "Some Comments on the State of General Systems Theory"
- No. 30. Buss, T.F., "Toward a Theory of Dimensions for the Social Sciences"
- No. 31. Miller, P.L., "Human Resources in Saudi Arabia"
- No. 32. Hainline, M.K. and Crain, R.C., "A Revised Agricultural Sector Simulation Model for Saudi Arabia"

#### IX. BUDGET

9.1	Total Amount of Funding	\$239,169.00
9.2	Expenditures and Commitments to date	\$188,061.56
9.3	Estimated Funds Required to Complete Contract	\$ 70,000.00
9.4	Estimated Date of Completion of Work	December 31, 1975



WORKING DRAFT 17<

A FURTHER DISCUSSION OF ISSUES

IN NEED OF RESOLUTION:

The Notion of a Sentence Writer

Paul A. Anderson  
Department of Political Science  
The Ohio State University

September 1974  
Research Paper No. 26

\* The research described in this paper  
was supported in part by the Advanced  
Research Projects Agency, Contract No.  
DARC 15 73 C 0197.

## Introduction

The purposes of this report are twofold: 1) a further elaboration and integration of the general approach to the modeling of national decision processes in Anderson (1974); and 2) a fairly careful discussion of the properties and operation of one component of that general model, the observation interface. As will be discussed more fully below, the nation is conceived as an adaptive goal seeking system. The system has goals for the configuration of its external environment. Observations are taken on that environment by the observation interface. The system then takes the pictures of that environment, evaluates it with respect to the system's goals, and through a process describes below, determines actions or behavior to be emitted that will bring the environment closer to the goal state. In order for a decision system having these properties to be constructed, there must be careful explication of 1) exactly what those properties are; 2) which system parts are responsible for their production, implementation and maintenance; 3) how those system components operate; 4) structural and information requirements necessary for the operation of the components; and 5) how the system components are linked through channels of communication and control (Cf. Deutsch 1966 on communication and control and Newell's (1973b) discussion of the control structure). The answers to those five questions will represent the transformation of the general notion of an adaptive framework of national decision systems from what Simon (1973) in somewhat different context has called an ill-structured problem to the specification of a well-structured problem -- a full blown process model of the national decision making process. Until the notion

of an adaptive goal seeking national decision system can be expressed in a well-structured manner the model cannot be built. Thus it is towards the transformation of general goal seeking notions about the behavior of national decision systems into a well-structured format that the efforts of this report are aimed. As will become more apparent below, one of the advantages of the basic conceptual framework upon which efforts are focused to express in a well-structured manner is the ability of the general framework to identify separable (not separate) clusters of issues. Separability does not make the specification of a well-structured problem easy; it does make it easier. The explication of the notion of the observation interface and a related conception called the sentence writer (SW) constitute the second portion of this report.

### The Big Picture

The basic components of the adaptive goal seeking framework for national decision systems is illustrated in Figure I. The components are: 1) the inner environment (IE); 2) the outer environment (OE); 3) the access interface (AI); 4) the observation interface (OI); and 5) the model (or image) of the OE (M). While the framework is discussed more fully in Thorson (1971) some comments seem in order. The interpretation of this framework into national decision system terms results in the following names being assigned the basic components: 1) the inner environment is the government of a particular nation; 2) the outer environment is potentially everything that is external to the governmental structure of the IE; 3) the observation interface are those portions of the bureaucracy that are responsible for the observation of the current state of the OE; 4) the access interface is composed of those components of the bureaucracy that are responsible for executing the actions that flow from the IE; and 5) the model is a shorthand term referring to how the various elements in the national bureaucracy responsible for the determination of decisions believe the OE works. It is important to note that the IE is defined strictly as the government. In contemporary theorizing in the field of international relations it is often the case that the unit of analysis is the nation, often expressed as the "political system." This view is best exemplified by the efforts of Rummel's (1971) status field theory and Singer's (1972) Correlates of War Project. The claim is not being made that the approach advocated here is strictly better than the specification of the unit of analysis as the nation. But it does seem to be the case that given the types of concerns expressed and the sort

of explanation and theoretical structure that are desired, the specification of the IE as the government is better than the specification of the IE as the nation. On the other hand, there are instances where it may be more efficient to view the unit of analysis as the nation as a whole. It is important to notice that taking the government as the unit of analysis does not imply that a choice has also been made between the unitary actor or bureaucratic/organizational (Cf. Allison 1971; and Allison and Halperin, 1972) representation of the government. Both are consistent with the adaptive framework. While the work reported here does view the national system as composed of several organizational actors the concepts developed are not restricted to a bureaucratic/organizational viewpoint. The second aspect that deserves mention is the definition of the outer environment as potentially consisting of everything that is external to the IE. This distinction is captured to a certain extent in Singer's (1961) discussion of the notion of levels of analysis. While our approach is a systems approach, it is not a systematic approach as characterized by Easton (1953), Kaplan (1957) or Parsons (1958). While part of the OE would in current international relations parlance be called the international system, this is not the same international system of which Kaplan et. al. speak. The system is the national government. What is called the international system portion of the OE is Kaplan's international system minus the nation that is under study. What is called the domestic political system in Easton's terms is also included in the OE in the same manner as Kaplan's system is included. While the physical environment of the national government consists of everything that is not part of that government, that physical environment represents only the

potential environment for the national decision system. The distinction is made here between the physical and effective OE's. That distinction rests upon what "really" impacts on the ability of the system to achieve its goals and what the system "thinks" has an impact on its ability to be goal attaining. If it were the case that the OE consisted of several independent subsystems not all of which could impact on the level of goal achievement, those subsystems independent of goal achievement would not be a part of the "real" environment. Thus in some ultimate sense, OE consists of those elements and the relations defined upon them that impact upon the level of goal attainment. From the perspective of the national decision system, the OE consists of those elements of the physical OE that are considered by the decision mechanism to impact upon goal attainment. Those portions of the physical OE that are "thought" to affect goal achievement (i.e., the relevant causal linkages) are expressed in the model (M) of the system of the OE. (In other discussions of this basic framework (Thorson, 1971, 1972; Bailey and Holt, 1971) the model of the OE was termed the image of the OE. As will be seen below, a major portion of this report is concerned with perceptions of the current state of the OE. In order to avoid confusion between the image of the current state and the image of the causal operation of the OE, the term model will refer to the system's conception of the causal operation of the OE, and image will refer to the perceived "snapshot" state of the OE.) Since it is logically possible (though not too probable) that both the "real" and "perceived" environment may in fact consist of everything that is external to the IE, at a maximum the OE could consist of the total physical environment. But since it is also possible (and certainly more probable) that only

a portion of the physical environment will in fact be relevant to the goal attaining ability of the system (both from the perspective of the "real" and "perceived" OE's) the OE may not constitute the entirety of the physical environment. The final comments concern the nature of the observation and access interfaces (OI and AI). Both the OI and AI are part of the IE, i.e., they are portions of the national governmental bureaucracy. Because they perform distinct sorts of functions (emit different classes of behavior) they represent separable components. A second important observation about the OI and AI is that they need not be distinct organizational members of the national governmental bureaucracy. Consider the Wage and Price Control Board. They had the responsibility of monitoring wage and price levels (OI) and they had the power to control wage and price changes (AI). But because there were two classes of behavior that the Board could emit (observation and access) the functions of the Board can be assigned to both the AI and OI.

While the operation of general goal seeking has been described in more detail elsewhere (Anderson, 1974), the following should be sufficient to provide a context for the development of what is called the sentence writer. The national decision system has a set of goals for the configuration of the OE. Under the control of the decision mechanism the OI takes observations on the OE and sends that information to the decision mechanism. The decision mechanism then compares the image it receives of the OE with the goal state. Based upon the perceived discrepancies between the goal state of the OE and the perceived state of the OE, the decision mechanism begins to search for behaviors it could emit that would cause the OE to move closer to

the goal state. The decision mechanism uses its causal model of the OE as a means for assessing the degree to which a given behavior or set of behaviors will increase the level of goal attainment. When the decision mechanism has discovered a set of behaviors it deems acceptable, it instructs the AI to emit those behaviors. Because of the manner in which the decision system uses its causal model, both the behavior and structure of the OI and AI are affected by the content of the model. The OI will only be sensitive to those features of the environment the M has identified as important. The behavior of the AI will obviously depend to a great deal upon the content of the M (in addition to the search procedure and the acceptability criteria used by the decision mechanism) to determine the behaviors that the AI will emit and the sorts of behaviors that the AI must have the capability of emitting. The center of attention of this report, the sentence writer, intersects the communication channel between the OI and the decision mechanism. The role that it plays in the operation of the system is the generation of sentences about the current state of the OE. The total system including the sentence writer and the decision mechanism is illustrated in Figure II, along with the lines of information and control. As can be seen in Figure II, the sentence writer does not replace the OI, but rather serves to transform the outputs of the OI before they reach the decision mechanism. By separating the OI and the SW (sentence writer) it is possible to separate the information that the system receives about the state of the OE and the interpretation given to that information. While the concept of a sentence writer could have been merged into the OI, by making the SW distinct from the OI conceptual clarity is increased. With this



separation, the OI is responsible for transmitting to the SW those aspects of the OE the decision mechanism, by the use of the M, deems relevant. The SW then takes the raw information and produces an interpretation or image of the current state of the OI. This notion is in line with some people's notion of the role of the intelligence community in the decision making process of the United States. Recent news stories indicate that one position currently held by policy makers is that the CIA and DIA should report only "facts" and leave matters of interpretation to the decision makers. While the notion of reporting only the "facts" is a spurious one (de Rivera, 1968) a certain amount of conceptual clarity and analytic tractability is gained by the separation of these empirically inseparable notions. Thus the OI scans the OE and detects what will be called "discrete facts" which describe the OE. These discrete facts include such things as the current price of oil, current wheat yield, and actions, statements of action, and statements of intention on the part of other governments in the OE. The sentence writer then takes these "objective" discrete facts and produces as output "discrete sentences" (which amount to direct translations of discrete facts) and "complex sentences." Complex sentences are either composed of discrete facts of inferences based upon discrete facts and the current knowledge state of the system. While the concept of a complex sentence will be discussed more fully below, the following should give some idea of the nature of a complex sentence: Suppose that the Saudi Arabian SW receives from the OI the discrete fact: "The United States announced that it would begin an immediate airlift to resupply Israeli material lost in the war." A complex sentence based upon that dis-

crete fact might be: "The United States is ignoring our threat of an oil embargo."

This concludes the introduction of the main theme. As was discussed in the introduction, the purpose of this report is to build a framework so that the problems involved in the construction of the decision system can be posed in a well-structured manner. That portion of the decision system that will attempt to be transformed into a well-posed problem is the linkage between the OE and the IE. Thus the central question for the remainder of this report is: What characterizes the process by which information contained in the OE is transmitted and transformed into a form such that the decision mechanism can use it in its evaluation of the current state of goal attainment as a guide for determining appropriate sorts of behaviors. Before continuing with a detailed discussion of the SW, the next section will be concerned with the general issues of the role of images, causal models, and perception.

### Images, Models, and Perceptions

The purpose of this section is to discuss in general terms some of the issues involved in the transmission of information from the OE to the IE. In the international relations literature attention has been paid to the concepts of perceptions and images. There have been studies of misperception (Holsti, 1965; Holsti, Brody, and North, 1965; Holsti, North, and Brody, 1968; Zinnes, 1968; Jervis, 1968); the role of belief systems (Holsti, 1962); the notion of images (Boulding, 1959, 1966; Jervis, 1970); the definition of the situation (Snyder, Bruck, and Sapin, 1962; Pruitt, 1965); and the process of selective attention (Pool and Kessler, 1965). Hendrix (1973) observes that efforts at the construction of intelligent machines (artificial

intelligence) generally make a distinction between two types of knowledge, state and process knowledge. These two notions fit very nicely into the conceptual system described above. State knowledge relates to knowledge about the world at certain instances in time (our image). Process knowledge is a body of information describing how one state may be transformed into another (our causal model). By making this distinction between process and state knowledge (or images about what is and the projection of what will be) a greater degree of conceptual clarity is gained. In the literature in the field of international relations, the distinction is seldom made. A notable exception is in de Rivera's The Psychological Dimensions of Foreign Policy (1968), where he emphasizes the distinction between the construction of reality (state knowledge) and the projection of the future (process knowledge). In fact, he devotes a chapter to each topic. There are certain conceptual advantages to be had by making this distinction (especially if one's goal is the design and construction of a mechanism that has the capability for perceiving and misperceiving). While incorrect images of the current state of the OF and faulty beliefs about how the OF responds to behaviors applied upon it both result in what is commonly known as misperceptions, there are different processes and influences involved in their production. To place this distinction more directly in an international relations frame of reference consider the surprise attack on Pearl Harbor and the Russian troop mobilization immediately prior to the outbreak of WWI. Wohlstetter's (1962) analysis of the Pearl Harbor perceptual failure on the part of the United States is clearly one of a faulty image of the current state of the OF. The signs were there that should have

indicated that something was in the making. The unintended response of Germany to the Russian mobilization during the 1914 crisis is attributable to a faulty causal model on the part of the Russians.

While the distinction between state and process knowledge is used in the artificial intelligence literature, when one examines the international relations literature cited above, one finds that very little attention has been paid to state knowledge as a separate entity. The role of a causal model often is not even mentioned. Pruitt (1965) discusses three sorts of "images" that constitute the definition of the situation: 1) predictions of the future behavior of the other nation; 2) perceptions of the basic characteristics of the other nation; and 3) conceptions of appropriate ways for dealing with the other nation. Predictions about the future behavior of other nations (the OE) is represented by the output from the causal model. Conceptions of appropriate ways for dealing with the other nation are outputs of the decision mechanism, resulting from the interaction between state knowledge, process knowledge, and the goal set. Pruitt's examples of basic characteristics are the concepts of friendly, hostile, weak, or trustworthy. Pruitt says that these characteristics are predicated of nations as a whole. They represent affective evaluations of other nations or actors. Rather than being part of either the image of the OE or the model of the OE, these evaluative assertions would be part of the current knowledge state. As will be made more explicit below, the SW only produces evaluations of the current OE. One does not directly "see" hostility, or trust. They are produced by the decision mechanism. The SW does have the capacity for generating sentences of the form: Nation X is still hostile, or

Nation Y has betrayed our trust. These sorts of sentences may change the current knowledge state by either reinforcing or contracting current evaluative assertions, but it is up to the decision mechanism to make those changes--the SW is a passive transmitter of the current state of the OE. The Stanford Studies (Holsti, 1965; Holsti, et. al., 1965, 1968; and Zinnes, 1968 among others) have not made the distinction between process and state knowledge or between perceptions generated by the SW and the perceptions generated by the causal model in conjunction with the decision mechanism. While they did code references to time, they did not have a conceptual framework that allowed them to manipulate those sorts of distinctions in a manner that would be of help in the construction of the SW. Jervis (1968) enumerates 14 hypotheses in misperception, but they either treat the notion of image in a non-systematic fashion, or they are concerned with the process of changing attitudes and beliefs (the current knowledge state). Boulding's treatment of images (Boulding, 1966, 1959) relies almost entirely upon the notions of a world view, evaluative assertions, and the problems of incompatibility among images. Holsti (1962) treats a belief system as a complete world view. While noting that included in a world view or belief system are images of what has been, is, and will be, he does not develop the structure and interrelations any further than that. He makes no distinction in the coding of the evaluative assertions of Dulles between perceptions of what the Soviet Union is currently doing, and perceptions of what the Soviet Union will do. He attempts to measure the current knowledge state of Dulles without investigating the structure of that knowledge state. Only the efforts of Pool and Kessler (1965) even begin to make the sorts of distinctions that are

being made here. Unfortunately, they go no further than to suggest several factors affecting the order in which stimuli from the OE are attended to. They do not discuss how statements describing the OE are integrated and processed so as to form a perception of the current state of the OE.

In view of the above comments, it should come as no surprise that the notion of perception of the OE as developed here is not a well-structured problem. Especially since the notion of a sentence writer appears to have received no discussion.

#### Giving Structure to the SW

Consider the SW for Saudi Arabia receiving the following messages from the OI:

- 1) The total wheat crop is X bushels
- 2) Y men are employed in farming
- 3) "Since Israel cannot continue to resist Egyptian aggression if it is not given replacement materials, we (the U.S.) will begin the immediate resupply of Israel."

The SW should be able to generate statements like the following:

- 1) Labor productivity is low
- 2) The U.S. will resupply Israel
- 3) The U.S. is ignoring our threat of an oil embargo
- 4) The U.S. is still pro-Israeli and anti-Arab
- 5) The U.S. is supportive of Israeli behavior
- 6) The total wheat crop is X bushels
- 7) Y men were employed in farming
- 8) Labor productivity is Z.

The output sentences 2, 6, and 7 represent discrete sentences (direct transfers with no interpretation). The rest are examples of sentences that require the interpretation of discrete facts. As noted above, these are called complex sentences. The first question is: What are the necessary properties of a SW that could generate these eight sentences? For the three discrete sentences, the SW must be able to

parse the sentence for the basic action and place it in the short term memory of the decision system. For the last two sentences that is a fairly trivial job; in fact the SW need only recognize the first two discrete facts as being in the form of discrete sentences. For the generation of sentence 2, the SW has a somewhat more difficult task. It must be able to "know" what the central theme of the sentence is. It must have the capability to recognize that the last clause conveys the basic action. Techniques by which the SW can make that determination will be discussed below. For the generation of the complex sentence "Labor productivity is low," the SW must have the capacity for manipulating the total wheat crop and total number of farm laborers to produce a value for labor productivity (complex sentence 8). In addition, it must also have the capability for determining whether that specific value for labor productivity is high, low, or moderate. In order for the SW to produce the complex sentence: "The U.S. is ignoring our threat of an oil embargo" the sentence writer must know that a threat of an oil embargo has been made. In addition to which, it also must have a means for assessing the relationship between the threat and the discrete fact from the OI. The SW must have a characterization of the past behavior of the United States and be able to recognize that the resupply of Israel is a continuation of that behavior if it is to generate complex sentence 4. If the SW is to generate the complex sentence 5 ("The U.S. is supportive of Israeli behavior.") the SW must be able to abstract from the discrete fact support for Israeli behavior.

One property of the SW immediately follows from above--it must have access to (and there must exist in the decision system) a record

of past incoming and outgoing information. In order to generate complex sentences 3 and 4, the SW must make reference to the past threat on the part of Saudi Arabia a characterization of past U.S. action. It will be recalled from the discussion above that the SW does not make evaluative assertions. The generation of sentence 4 would seem to contradict that statement. It does not. The SW in this instance is not generating an evaluative assertion, but rather interpreting the behavior of the U.S. in light of a current evaluative assertion. The distinction is subtle, but crucial. The assertion of a general evaluation of the behavior of another nation requires the ability to observe the general pattern of behavior over an extended period of time. The SW does not have that capability. The SW receives only a single time slice, which it must interpret with respect to the current knowledge state of the system. Only the decision mechanism has the ability to observe many points in time simultaneously. Since the SW has access to the current knowledge state (both the short term and long term memories) it can make comparisons between the discrete facts and the current knowledge state.

The technique for the generation of the sentences concerned with labor productivity are relatively simple. The SW must "know" that if it "sees" values for yield and manpower it divides the crop yield by the number of farm employees to produce a value for labor productivity. A comparison then would be made against some standard for the evaluation of whether or not the level of labor productivity was high, medium, or low.

While the generation of sentences concerning labor productivity are simple and straight forward, the production of sentences 3, 4, and 5 are another matter entirely. As was discussed in Anderson (1974),



communications between various nations is linguistic. Communication takes place within a strictly defined subset of English. The grammar of the language will determine whether or not the sentence is well-formed, but it will not convey the meaning of the sentence. The SW and the decision mechanism must have the capability for the understanding of sentences in that language. In an effort to explicate what is required for the understanding of sentences in a language (and how the SW does it) attention will first be paid to some very specific and restrictive examples of how the process of understanding takes place. Once the skeleton of the process of semantic interpretation takes place, the discussion will turn to the generation of semantic interpretations of sentences in a more general frame.

The key to the semantic interpretation of sentences is the existence of a set of rules or procedures that define a set of manipulations on the basic sentence. This set of rules will be called the linguistic axioms or model. The elements of the linguistic axioms can be divided into two categories--those that are syntactically based and those that are semantically based. The syntactic axioms are responsible for the recognition phase (Cf. McKeeman et. al., 1970) of the process. The recognition phase determines whether or not a given sentence is a member of the language. Only those sentences that conform to the grammar of the language have possible semantic content. The SW must recognize a string of symbols as being a legitimate sentence in the language before it can begin the process of determining its meaning. Consider the following two sentences:

- 1) Colorless green dreams sleep furiously.
- 2) Furiously sleep ideas green colorless. (from Chomsky, 1957).

Sentences 1 and 2 could both be considered nonsensical (no semantic

content), but only sentence 1 would be considered grammatical. (Although as Wilks (1972) points out there is considerably less than total agreement on the subject.) A grammatical sentence assures that information (in the semantic sense) could be conveyed by the sentence, but it does not guarantee it. In other words, the property of being grammatical is necessary but not sufficient for the transmission of semantic information. It is also the case that the sharing of a common grammar does not insure identical semantic interpretations will be given to a sentence by two receivers. The semantic axioms are in a sense independent from the syntactic axioms. Consider the following sentence: "They are flying planes." Does "they" refer to the planes or to the individuals who are flying the planes? With respect to the English grammar this sentence is ambiguous. As will be discussed more fully below, this partial independence of syntactic and semantic axioms provides one means for the generation of misperceptions about the OE. If the meaning that was intended to be transmitted by the sender were the first sense of the above sentence and the receiver thought that "they" referred to the individuals who were flying the planes, there would be a misperception. But while there is a certain independence in the relationship between semantic and syntactic axioms, there is also a certain degree of dependency. This results from the fact that the semantic axioms are only applicable to grammatical sentences.

An appropriate question might be: What does it mean to state that semantic axioms are applicable? It turns out that the notion of applicability (or how the semantic axioms manipulate discrete facts) is central to the generation of semantic interpretations. Looking at the three discrete facts that were exhibited as examples of inputs to

the Saudi SW and the eight sentences produced as outputs, it would seem to be the case that the input sentences in some manner imply the output sentences. The total wheat crop of X bushels and the Y men employed in farming seem to imply that labor productivity is (say) high. The fact the Saudi's had issued a threat of an oil embargo and the fact that the U.S. announced that it intended to resupply Israel would seem to imply that the U.S. was ignoring the Saudi threat. That is the argument being made here. By using the notion of a set of linguistic axioms (both semantic and syntactic) that intuitive implication can be more more explicit. Specifically, the output sentences can be conceptualized as deductions about the current state of the OE with the semantic model as a set of axioms and the current knowledge state, discrete facts, and sentences (both discrete and complex) serving as the premises. Thus given the linguistic axiom: If there has been a threat of an oil embargo made to a country if that country aids Israel, and a country says that it intends to aid Israel, then that country is ignoring the threat of an oil embargo. If knowledge of the threat is in the current knowledge state of the system (the memory); if the U.S. generates a sentence (which becomes, from the perspective of the Saudi SW, a discrete fact) that the U.S. will aid Israel; then the conditions of the axioms are satisfied. The deduction can then be made that the U.S. is ignoring the Saudi threat of an oil embargo. Structurally this condition--deduction, or if-then form of the axioms--fits very nicely into the production system (see Anderson, 1974; and Newell, 1973a) conception that is planned for the construction of the decision system. A production system consists of a set of statements called productions. A production is a

statement of the form condition--action. If the condition is true then the action is taken by the system. In terms of the SW, if the conditions of the axiom are true, then the deduction is made. This structural similarity between production systems and the linguistic axioms has an additional desirable property besides theoretical elegance. From Klahr (1973) a production system obeys several operating rules. Those relevant to this context include:

- i. The productions are considered in sequence, starting with the first.
- ii. Each condition is compared with the current state of knowledge.
- iii. If a condition is not satisfied, the next production rule in the order list of production rules is considered.
- iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).

These four rules are easily interpreted in the linguistic axiom context. Just substitute linguistic axiom for production, and action would be replaced by deduction or semantic inference. Now consider the propositions about selective perception found in Pool and Kessler (1965):

1. People pay more attention to news that deals with them.
2. People pay less attention to facts that contradict their previous views.
3. People pay more attention to news from trusted, liked sources.
4. People pay more attention to facts that they will have to act upon or discuss because of attention by others.
5. People pay more attention to facts bearing on actions they are already involved in, i.e., action creates commitment.

By having the operation of the SW and the linguistic model or axiom set follow those four production system rules, the five propositions that Pool and Kessler identify as being aspects of the process of selective properties can be exhibited without the explicit invocation of separate structure and process. In essence, by relying upon the

notion of production systems we get something for nothing. Thus not only do production systems represent an elegant solution to the specification of the operating rules of the system, they also have embodied within them a great deal of theoretical power. Take Poll and Kessler's second proposition. By placing those linguistic axioms that would result in the generation of sentences that contradict currently held views at the bottom of the ranked list of axioms, the system can be made to behave as if it paid less attention to facts that contradict its previous views.\* The propositions stating that people pay more attention to news that deals with them, to facts that they will have to act upon, and to facts bearing on actions that they are already involved in, can all be reinterpreted as stating that a decision system pays more attention to facts, news, and actions that affect the system's level of goal achievement. The placing of those linguistic axioms relating to the goals of the decision mechanism near the top of the list of axioms will cause the predication of those three propositions to the behavior of the system. By making the conditional portions of the linguistic axioms contingent upon the amount of trust or degree of liking attributed to the source of the message, behavior consistent with the proposition that people pay more attention to news from trusted, liked sources can be exhibited. The realization of this proposition can be accomplished by placing the "trusted axioms" higher up in the list of the linguistic axioms than the "distrusted axioms." The realization of this last proposition implies that by using the production system notion to exhibit the phenomena of selec-

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\* See Anderson (1974) for a discussion of how the ordering of productions will produce this result.

tive perception we are not getting something for nothing. The generality and elegance of the set of linguistic axioms is sacrificed for the production of an empirical proposition. While a formal linguist would decry this convolution of his formal system, we are not giving up anything of great consequence. Compared to the alternative of assigning a "salience score" the linguist's dismay is the IR theorist's delight.

The realization of the three propositions of selective perception that were interpreted as involving the goals of the decision system highlight an additional condition that must be placed on the form of the outputs that the SW generates. The sentences produced by the SW are intended to be used by the decision mechanism as 1) a description of the current state of the OE; 2) a means for determining the level of goal achievement; and 3) inputs to the causal model to produce forecasts of future states of the OE contingent upon the application of sets of behavior by the AI. These three uses (especially uses 2 and 3) place demands upon the characteristics of the SW outputs. If the decision mechanism is to use SW outputs to determine goal achievement, the sentences of the SW must be comparable to the statements of the goals of the system. If the sentences generated by the SW are to be used as part of the inputs to the causal model of the OE, they must be in a form such that the M can digest them. Thus in the construction and specification of the linguistic axioms attention must be paid to what will be done with the output sentences. The design process must show sensitivities to the goals of the system, the sorts of inputs the causal model is capable of processing, and the information processing capacity and capability of the decision mechanism.

The last topic that will be discussed before a more thorough discussion of the syntactic parsing and semantic inference techniques is perhaps one of the most fundamental--that of control. Prior to this there has been some discussion of the flow of information within the system. But what Newell (1973b) has called the control structure has only informally been discussed. While the challenges of communication and information do represent important aspects of the control structure, the concept of control channels changes a basically passive adaptive system into an active adaptive system. Until channels of control are specified, the system is only behaving as if it were adapting. Without the capability to change its outputs and modify its images as a result of past experience the apparent ability of the system to adapt to its environment is only that--an illusion. It must learn. The system must have the capacity to internalize past experience. The system can learn only with the existence of feedback loops and control channels. The system must have the capacity to modify its causal model of the OE. It must be able to change its perceptions of the basic characteristics of other nations. Its perceptual system must show a sensitivity to past experience. While Thorson (1972) has shown that there exists no adaptive system that can adapt to all environments, the class, number, and complexity of the environments that the system can adapt to and or adapt is a function of its ability to learn. The basic lines of control and self-modification are shown in Figure II. Of the numerous channels of control pictured in Figure II, only those dealing with the SW will be discussed here. (The others must wait the well-structuring of those system components affected.) With the ability of the system to change its current knowledge state, it becomes necessary that certain portions

of the SW be open to modification by the decision mechanism. Consider the second proposition dealing with selective perception. It states that people pay less attention to facts that contradict their previously held views. When the system's "previously held views" change, the operation of the SW must also reflect that change. It will be recalled that this proposition was realized in the SW by ranking those linguistic axioms that would generate sentences contradicting currently held views below those that generate sentences consistent with the current knowledge state. Thus the ordering of the linguistic axioms under the productions system-like control must be subject to modification. The three of the selective perception propositions interpreted as being sensitive to the goals of the decision system will also necessitate the rearranging of certain linguistic axioms as the goals of the system are modified. Since the proposition dealing with trusted or liked sources of information was realized by making axioms contingent upon the current evaluation of the source, as the state of knowledge of the system changes (which includes the current evaluative assertions) will automatically be reflected in the behavior of the SW without further modification of the SW. If the system has the ability to perform major modifications of its causal image of the OE and the introduction or elimination of goal statements, the system must have the ability to do more than simply re-order the linguistic axioms. It must have the capability to delete axioms and generate new ones. (It is doubtful that the system will have the ability to make such major modifications in light of the technical difficulties in the realization of that power. At most, we can strive for the design of a "smart" machine. The design of a truly "intelligent" machine will probably have to wait the resolu-



tion of certain fundamental issues in the field of artificial intelligence. The full specification of the process of self-modification is the topic for another report. Before we can talk about the process and techniques of self-modification, that which is to be modified must be well structured. As of yet, the SW is not well structured enough to permit that sort of inquiry.

### Semantics, Syntax, Parsing, et. al.

The purpose of this section is not to present an algorithm that will perceive discrete facts and produce semantic interpretations as outputs. While there is every reason to believe that such a presentation will eventually be made, the specification of the algorithm will be difficult--but it is not impossible. Before such a specification can be made certain issues must be resolved and certain decisions must be made. This section represents a first attempt to specify what must be overcome in order to specify a complete and effective (in the sense of computable) procedure for the mechanical generation of semantic interpretations.

The first and most obvious element that must be specific if one is to talk about the generation of semantic inferences is the thing that the semantic inferences are defined upon, language. Figure III is a working version of a language structure. It modifies a less sophisticated version presented in Anderson (1974). It should be emphasized that this structure is not a finished product. There are several respects in which it is lacking. The most obvious of which is that there is no specification of the admissible actors or of the admissible actions. It is only a list of 20 sentential forms. Furthermore in order to serve as the basis for the specification of a

SW, it must be presented in what is called a phrase structure format. As it is presently given, this is not a true grammar--only the skeleton. A phrase structure grammar has as its basis a set of phrases formed from the concatenation of other phrases and words. Consider a portion of a phrase structure grammar for English. One of the basic structures of that grammar might be a "simple sentence." A simple sentence might be defined as a "subject" followed by a "predicate." Under this structure, a sentence like: "He threw the election." would be recognized structurally as being a simple sentence, with "He" as the subject and "threw the election" as the predicate. The predicate might further be broken down as being a transitive verb and a direct object. This process of breaking down a sentence is called parsing. The first use that the grammar is put to in the semantic interpretation process is the determination of whether or not the sentence is grammatical--whether or not it is in the language. The process of recognition proceeds in a manner like the following: The sentence is scanned to determine the recognizable phrases, i.e., transitive verbs, conjunctions, adjectives, adverbs, etc. Then the sentence is re-scanned to determine whether or not those phrases can be chunked to form other phrases, e.g., a transitive verb followed by a direct object is a predicate. This process of chunking continues until one of two things happens, either the sentence is reduced to one chunk or it is not. If the sentence is fully reduced it is grammatical, i.e., part of the language. If the sentence is not reducible to one chunk, the sentence is not in the language. If the goal symbol happened to be a simple sentence, then "He threw the election" could be reduced to one chunk. On the other hand, "He the election threw" would not be

reducible to a simple sentence. This is exactly the type of process used by programming language compilers when they reject statements of a program. A compiler can recognize that  $a = b + c$  is a legitimate sentence, where  $= a c b +$  is not. This process of syntactic analysis is the least problematic of the problems that are faced in the specification of the SW. In fact, given a well-formed grammar, the syntactic analysis of a language is quite straight forward. Numerous books have been written on the subject, the techniques and requirements are well-defined, and there even exist programs which will take a grammar as input and generate a program that will do the syntactic analysis. As a further illustration of how this syntactic recognition process works, consider a sentence from the language specific in Figure III: "Since Israel cannot resist Egypt if Israel is not resupplied then the U.S. will resupply Israel." From an inspection of Figure III it can be seen that this sentence has the same structure as sentential form 13: Since \_\_\_\_\_ then \_\_\_\_\_. The quasi-phrase structure parse of this sentence is given in Figure IV. The following is a description of that parse: On scanning the sentence from left to right, the first complete sentential form that is recognizable is that of "Israel cannot resist Egypt" which is form 1. That phrase is replaced with a marker indicating a type 1 phrase. The scanning continues from left to right. The next phrase to be recognized is "Israel is not resupplied," or ACTOR is not ACTION. A marker for sentence type 6 replaces that phrase. The next phrase is that of form 3. At this point the partially parsed sentence looks like this: SINCE (1) IF (6) THEN (3). Since the end of the input string has been reached, but the reduction or chunking is not complete, the process starts

over from the left on this new string. The next recognizable phrase is that of \_\_\_\_ IF \_\_\_\_, which is form 18. The "(1) IF (6)" part of the string is replaced by (18) resulting in the following string: SINCE (18) THEN (3). The scanning is restarted from the left once more. This time the whole of the remaining string is recognized as a sentence of the type SINCE \_\_\_\_ THEN \_\_\_\_\_. The entire string is replaced by the marker (13), and the recognition phrase is complete, the sentence is part of the language. Notice that in the process of recognition the original sentence has been lost. This is overcome by keeping a copy of the original sentence in memory. That original sentence plus the entire phrase tree is passed on to the next stage in the process, that of synthesis. Before moving on to the topic of synthesis (which is really at the heart of the matter) a couple of comments are in order about recognition, grammars, and the particular quasi-grammar exhibited in Figure III. Upon inspection of the grammar, it can be seen that it represents a very restricted language. Not everything is expressable in that language. That is how it should be. The sort of grammar being sought is a grammar that allows one to say enough, but not too much. While it might be nice to use the entire English language as the basis for the communication in the specification of the decision system, elegant prose is not our goal. Attempts at the recognition or translation of natural language have proven to be dismal failures. No one has yet succeeded in writing down the grammar for English. Mechanical translations have produced more garbage than anything else. Natural languages cannot (as of yet) be processed mechanically. The problems in doing so appear (to some) to be insurmountable. But it has been possible to design, construct

and run machines that can handle artificial languages and/or very specific subsets of natural languages (Cf. Wilks, 1972; Minsky, 1968; and Siklossy and Simon, 1972). Thus it is impracticable to use English as the basis for the language specification--but it can be done with a subset of that language. The selection of that subset is (and probably forever will be) an ill-structured problem. The subject must be able to express what must be expressed, but on the other hand, the smaller the scope of the language the easier it will be to produce a mechanical realization of it. These two trade-offs are responsible for the provisional status of the language specified in Figure III. It is not known how acceptable that language is. The ability to recognize an acceptable language requires structure. (It might seem circular that before giving structure to part A of the system, part B must be structured, but before part B can be structured, part A must first be structured. To a large extent that is true. A provisional structure must first be guessed at. Then through the interaction of the specification of the various system parts, that provisional structure can be modified. But the closer that first guess is to the "true" structure, the quicker will be the convergence. It is by discussing the holes in the entire system before specifying the provisional structure for one of the components, can the chance that the provisional guess is close to right be increased. We will simply have to deal with ambiguity for a while.)

To help illustrate some of the problems faced in the specification of semantic inferences, consider what could be characterized as a brute force approach to the problem. One obvious way to get the semantic interpretations would be to list all possible sentences and

determine the permissible semantic inferences. That will not work for several reasons. First of all, the quasi-grammar in Figure III defines an infinite number of sentences. The recursive property of the grammar which accounts for its power implies an infinite number of sentences in the language. Secondly, as was indicated above, the semantic interpretations of a given sentence depends upon the current state of knowledge of the system. As the current knowledge state changes, the SW's semantic inferences should reflect those changes. Semantic interpretations depend upon the goals of the decision systems. As the amount of goal achievement varies, so could the semantic interpretations vary. A decision system that constantly experienced a low degree of goal achievement could view the world in a different light than a "top-dog." The phenomena of rising expectations followed by a decrease in goal achievement could cause semantic inferences to change. From this it follows that the rules of semantic interpretation must be sufficiently general so as to produce different interpretations under certain classes of differences in the state of the system. As another illustration of the issues involved, consider these four sentences in the language of Figure III: The U.S. will resupply Israel so that Israel can resist Egypt. Since Israel cannot resist Egypt if Israel is not resupplied then the U.S. will resupply Israel. The U.S. will resupply Israel because Israel cannot resist Egypt if Israel is not resupplied. The U.S. will resupply Israel. The Saudi Arabian SW should produce identical sentences given the reception of any of the four sentences. As can be seen from an inspection of the grammar, each of these four sentences is a different sentential type. One could perhaps argue that

the grammar is too sophisticated for its purposes. It may not be necessary to have four ways of expressing the same "thought." The degree of sophistication of the languages hinges upon what sorts of information are required for the decision mechanism to operate. It is possible that the decision mechanism only needs very simple statements of action to generate decisions. If it happened to be the case that the decision mechanism only needed simple statements as inputs, but was capable of generating more sophisticated statements as outputs, then a dual level of sophistication could be employed. It would be useful, if only for the purposes of "seeing what was on the decision mechanism's mind," to have sophisticated sentences generated. The SW could easily strip away all of the "unnecessary" sophistication. This would simplify the specification of the SW. No matter what the capabilities of the decision mechanism may turn out to be, it is clear that the grammar in Figure III represents a sort of upper bound on sophistication.

One possible approach to the specification of the SW is loosely analogous to the operation of the General Inquirer (Stone, et. al., 1966). The General Inquirer computer program for the content analysis of statements has as its basis a dictionary. Depending upon the relevant "cognitive dimensions," each word in the dictionary is assigned a score on those dimensions. For example if the dimensions were active-passive, strong-weak, and good-bad (Cf. Osgood, 1962) the word "bomb" would be given a score indicating very active, strong, and bad. The General Inquirer system "tags" all of the words in the text, manipulates the scores (by adding and or averaging them) and generates "perceptions." Essentially what has been done in the con-

struction of the dictionary is that the words have been assigned to equivalence classes. All those words having the same scores on the dimensions are members of the same equivalence class. The SW could also be based on a similar procedure. The SW would be provided a dictionary, but this dictionary would not contain only words.

It would probably contain more phrases than words. The linguistic axioms would provide the manipulation rules for breaking down the input strings into "elemental chunks" (syntax) and for the assignment of meaning according to the equivalence classes to which the elemental chunks belong (semantics). The SW would then take the evaluations of those elemental chunks and by applying an additional set of rules, produce a general semantic evaluation. If it turns out that the decision mechanism does not need a sophisticated language to operate, this process of re-combining could be avoided. Consider the simple sentence: The U.S. will initiate an immediate airlift of replacement parts, ammunition, and planes to Israel. Replacement parts, ammunition, and planes could all belong to the equivalence class of "material support." The basic "thought" or expressed meaning of that action is: U.S. (material support) Israel. If there were linguistic axioms of the form: (country) (material support) Israel  $\rightarrow$  (country) pro-Israel, anti-Arab, the semantic inference can be made. If more sophisticated statements are received as input, appropriate syntactical rules or axioms could handle the de-composition. The question is whether or not the semantics of the sentence are invariant under this process of de-composition. If more sophisticated sentences were required for input into



the decision mechanism, the question is: whether or not the semantics of the original sentence are invariant under decomposition and re-composition? The use of the techniques of a dictionary, elemental chunks, decomposition, and recomposition, seems to hold promise. By using these notions the basic requirements and properties of a SW can be identified. The question is: Can a set of linguistic axioms be specified that will meet the requirements?

Conclusion: How Well-Structured is the SW?

The purpose of this report has been to begin the process of specifying a well-structured problem--the sentence writer. In assessing how far we have come (and how far we have to go) Simon's criteria for a well-structured problem are of use:

[A] problem may be regarded as well-structured to the extent that it has some or all of the following characteristics:

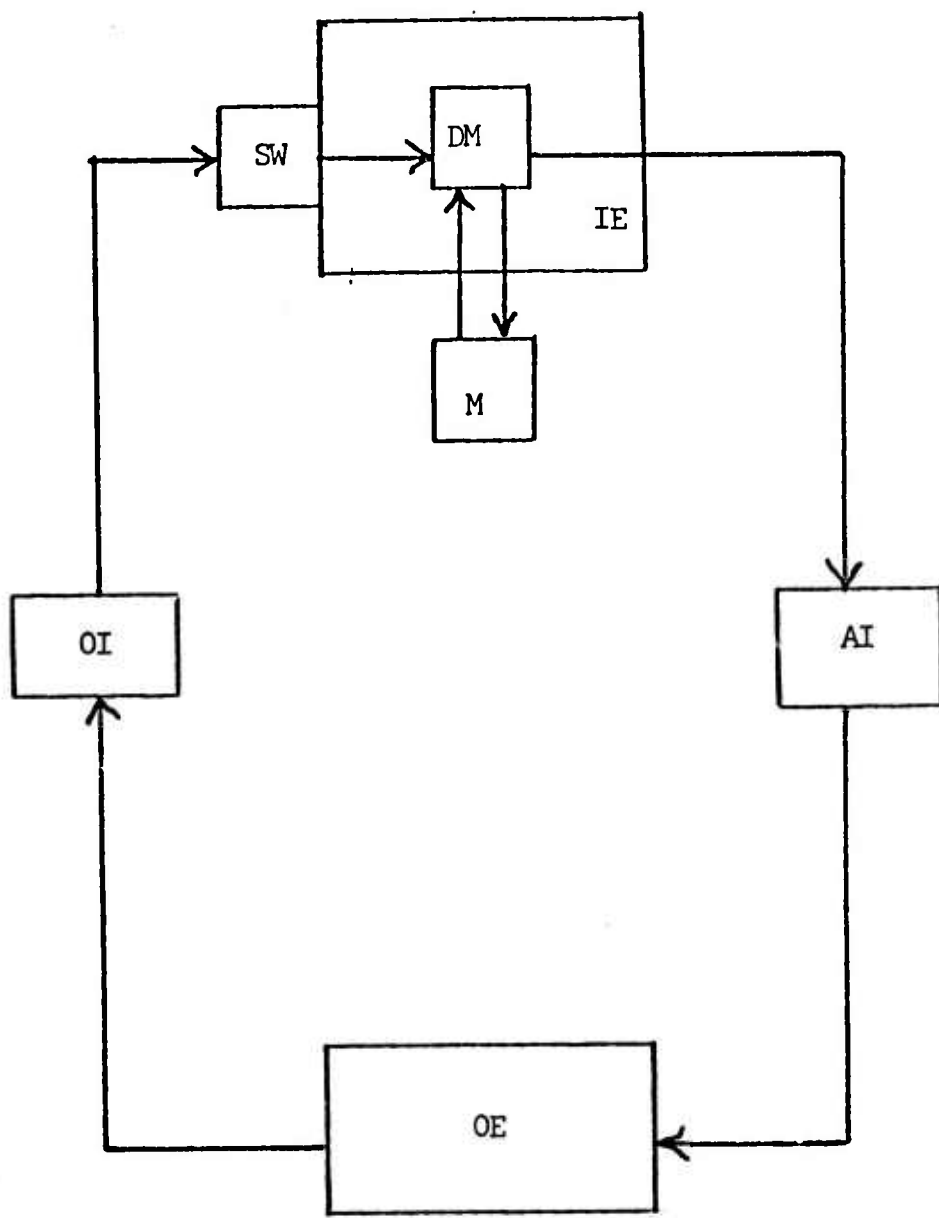
- 1) There is a definite criterion for testing any proposed solution, and a mechanizable process for applying the criterion.
- 2) There is at least one problem space in which can be represented the initial problem state, the goal state, and all other states that may be reached, or considered, in the course of attempting a solution of the problem.
- 3) Attainable state changes (legal moves) can be represented in a problem space, as translations from given states to the states directly attainable from them. But considerable moves, whether legal or not, can also be represented--that is, all transitions from one considerable state to another.
- 4) Any knowledge that the problem solver can acquire about the problem can be represented in one or more problem spaces.
- 5) If the actual problem involves acting upon the external world, then the definition of state changes and of the effects upon the state of applying any operator reflect with complete accuracy in one or more problem spaces the laws (laws of nature) that govern the external world.

- 6) All of these conditions hold in the strong sense that the basic processes postulated require only practicable amounts of computation, and the information postulated is effectively available to the process--i.e., available with the help of only practicable amounts of search.

(Simon, 1973:183)

It should be pointed out that the problem solver that Simon refers to is a computer program, hence the references to amounts of computation and mechanization. The purpose here is not to program a SW. At this point in time we are the problem solvers and the problem is the SW. (At some point in time, Simon's notion of well-structured will also apply to the problem that the decision system faces--that of adapting to its environment.) The problem space that Simon refers to is the manner in which we have conceptualized the SW. The states refer to their resolution. The "laws of nature" for the SW turn out to be the laws of logic. References to computation and information refer to the scope of the problem to be solved. If a SW cannot be conceptualized in manageable sized chunks, and if solutions to the issues cannot be reached within "reasonable" amounts of search and effort, the problem is not well-structured enough to permit the construction of a working SW. By comparing this list with the content of this report, it can be seen that we have not reached our goal--structure still eludes us. But all is not hopeless. The problem space is much more clearly specified, the basic issues and requirements have for the most part been identified. It does not appear that the SW will require "excessive amounts of computation" to conceptualize. We have what amounts to an initial problem state. The goal is known. It must only be realized.

FIGURE I

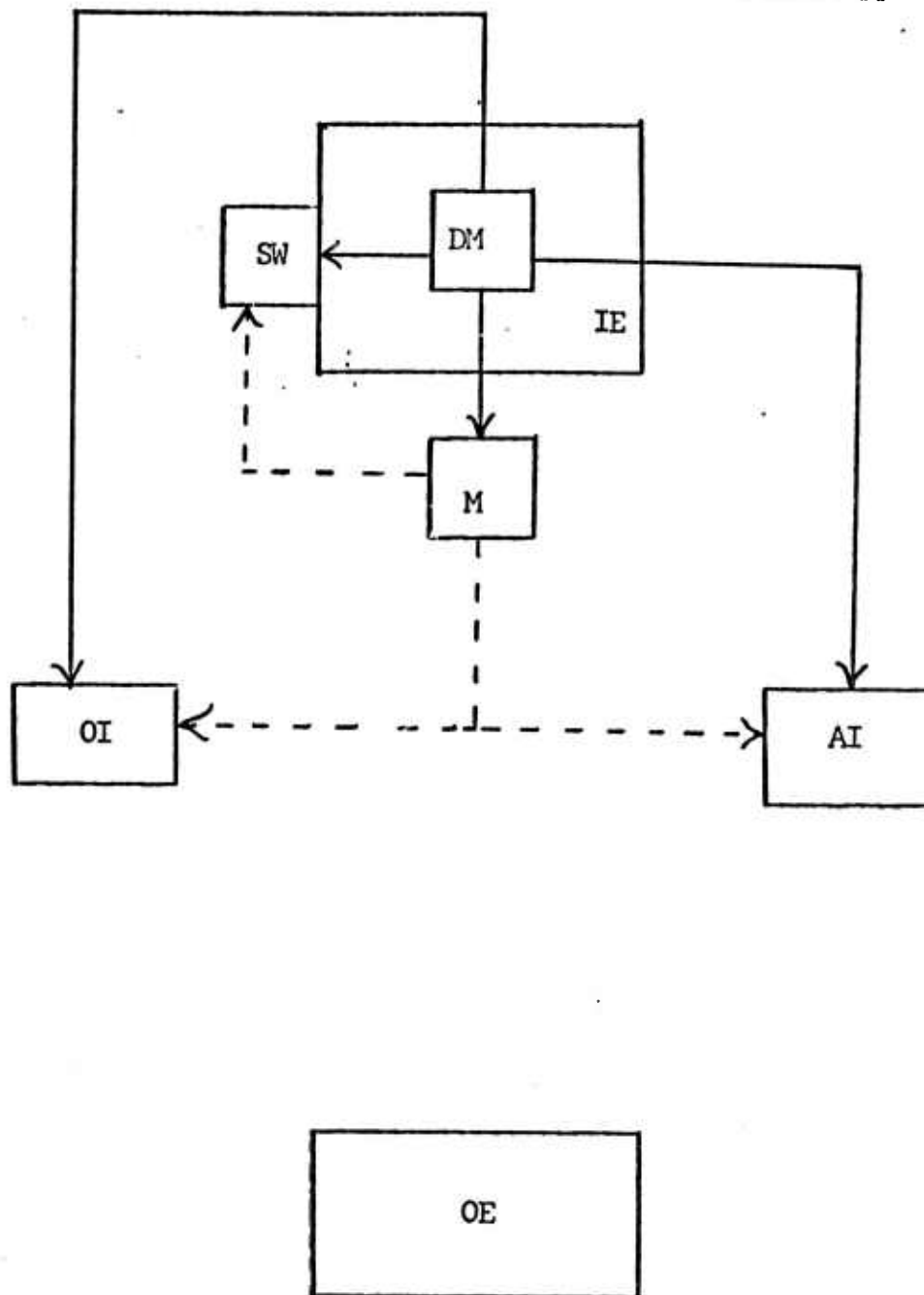


IE: Inner Environment  
 OE: Outer Environment  
 AI: Access Interface  
 OI: Observation Interface  
 SW: Sentence Writer

DM: Decision Mechanism  
 M: Model of the OE

FIGURE II

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IE: Inner Environment

OE: Outer Environment

AI: Access Interface

OI: Observation Interface

SW: Sentence Writer

DM: Decision Mechanism

M: Model of the OE

— : Direct Control

- - - : Indirect Controlling Influence

FIGURE III

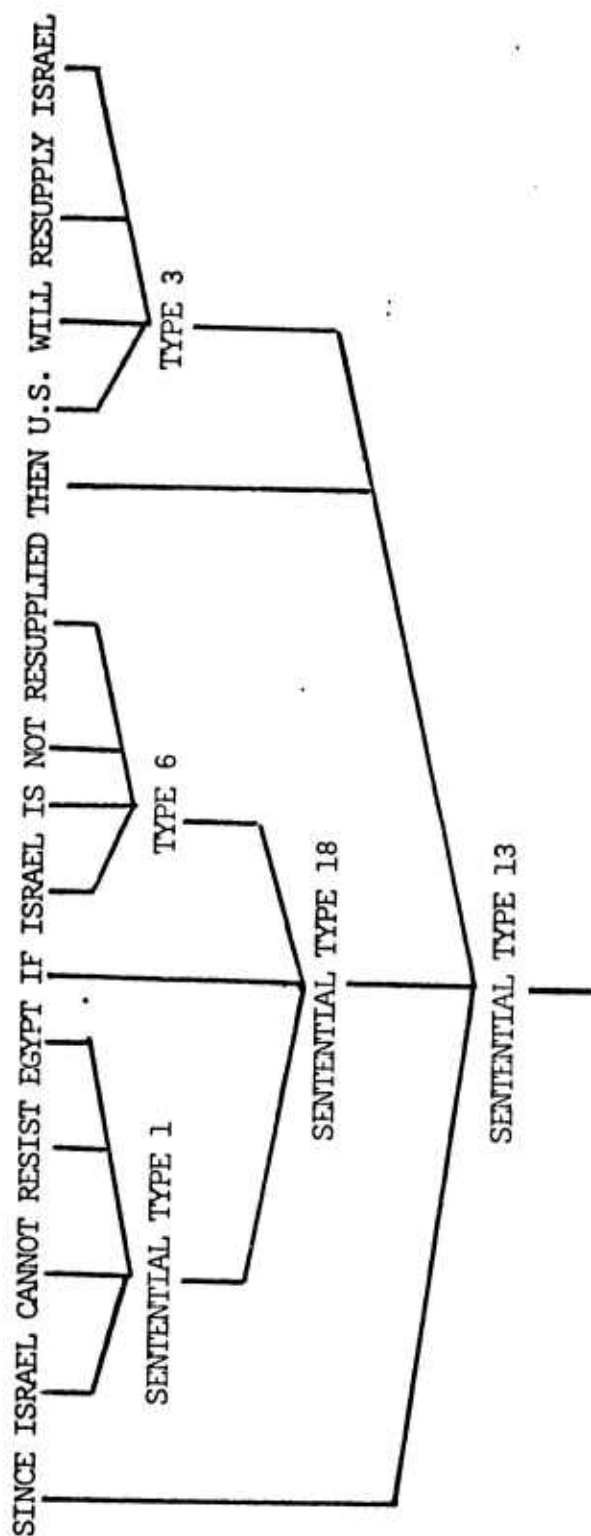
- 1: <ACTOR> <CAN|CANNOT> <ACTION> <ACTOR>\*
- 2: <ACTOR> <COULD|COULD NOT> <ACTION> <ACTOR>\*
- 3: <ACTOR> <WILL|WILL NOT> <ACTION> <ACTOR>\*
- 4: <ACTOR> <SHOULD|SHOULD NOT> <ACTION> <ACTOR>\*
- 5: <ACTOR> <DID|DID NOT> <ACTION> <ACTOR>\*
- 6: <ACTOR> <IS|IS NOT> <ACTION> <ACTOR>\*
- 7: WILL <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>\*
- 8: SHOULD <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>\*
- 9: DID <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>\*
- 10: IS <ACTOR> <DOING|NOT DOING> <ACTION> <ACTOR>\*
- 11: CAN <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>\*
- 12: IF <...> THEN <...>
- 13: SINCE <...> THEN <...>
- 14: <...> BECAUSE <...>
- 15: <...> SO THAT <...>
- 16: <...> AND <...>
- 17: <...> OR <...>
- 18: <...> IF <...>
- 19: <...> AND NOT <...>
- 20: <...> OR NOT <...>

\* Optional; the actor (target) may be omitted.

| means that one of the two choices should be selected.

... means that any one of the 20 sentential forms may be selected.

FIGURE IV



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MODELING CONTROL STRUCTURES FOR  
COMPLEX SOCIAL SYSTEMS\*

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## MODELING CONTROL STRUCTURES FOR COMPLEX SOCIAL SYSTEMS

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### Abstract

Basic systems concepts are reviewed and used to define artificial systems. The artificial system structure is given both a control theoretic and a "political science" interpretation. Under the political science interpretation, the inner environment becomes the government and the outer environment the system external to the government. The concept of "complexity" is discussed from a systems theoretic perspective and implications are drawn for the modeling of governments as control structures. Several principles - hierarchical organization, multiplicity of goals, and potential redundancy of control - are offered to aid in restricting the class of control structures possibly admissible as models of governments. Production systems are proposed as a possible approach to the development of control structures which satisfy these principles. The notion of a production system is illustrated with a simple example.

A number of scholars have employed "systems concepts" in investigating phenomena from the domain of international relations (e.g., see Rosenau, 1970; McGowan, 1970; Forrester, 1971; Phillips, 1974). However, the number of systems oriented researchers who have explicitly considered what might be called the "control structures" of the social systems they study is relatively small. For example, Forrester's well known "World Model" contains no explicit decision making mechanisms and unless run interactively, his simulation is mechanistic.

Yet even casual observers of the international scene are often struck with the seemingly adaptive nature of national foreign policy behaviors. Alliances often seem to shift in apparent response to changing "realities" such as a perceived scarcity of crude oil. Yet, as with most all adaptive mechanisms, the range of adaptation has limits. Some policies (perhaps the U.S. policy toward China would serve as an example) change very slowly and the reasons seem more related to the internal politics of government than to the external environment the government is attempting to deal with.

If the sorts of behaviors described above are taken to be roughly descriptive of international politics, then clearly any theory of, say, foreign policy

behavior must be capable of accounting for these kinds of observations. Such an accounting requires a careful consideration of the control structures of the systems being studied. The purposes of this paper will be to explicate what is meant by control structure in this context and to suggest some organizing concepts of possible use in modeling these structures.

### § 1 Introduction

In order to put the following discussion into a unified perspective, it will be helpful to provide an overview of some basic systems concepts. Since these concepts are treated in detail elsewhere, what follows will simply be a review of basic definitions.

Following Mesarovic (1967) systems will be viewed abstractly as set-theoretic structures. More specifically:

"Let a family of objects be given  $V = \{V_i | i \in I\}$  where  $I$  is the index set for the family  $V$ . A system  $S$  is simply a relation defined on  $V$ , i.e.

$$S \subseteq \times \{V_i | i \in I\}$$

where  $\times$  indicates cartesian product.

On the basis of this definition, general systems theory becomes simply a general theory of relations. Following a formalization approach, one starts from such a general notion of a system and then proceeds to assume more structure for the object  $V_i, \dots, V_n$  and investigates the properties induced by the relation  $S$  (p. 223)."

In this context, the family  $V$  is simply a collection of sets of objects  $V$ . The set  $I$  is used to index the sets in  $V$ . The use of object here may be thought of as a generalization of the notion of a variable. The members of a particular object set then become possible values or "appearances" for the object. As an example, a student of international politics coding the affective aspect of national foreign policy behaviors as being either friendly or hostile could be viewed as measuring the object named affect. The elements or appearances of the object would be { friendly,

hostile). Most systems of interest will have more than one object and an appearance of a system can be given by listing the appearance of each object in the system. In the case of dynamic systems (those directly parameterized by time) a concern is often with relating system appearances at one time to system appearances at future or previous times.

From this general definition of system it is possible (Mesarovic, Macko, and Takahara, 1970) to move to a familiar "black box" view of a system where the object family  $V$  is broken into an input set  $U$ , and output set  $Y$  and a state set  $Z$ . The system can then be rewritten as:

$$S: Z \times U \rightarrow Y \quad (1)$$

That is, the output of the system is a function (in the mathematical sense) of the input and the present state of the system. A minimal description of a system in this sense requires identifying the set of input objects ( $U$ ), the set of state objects ( $Z$ ) and the set of output ( $Y$ ) objects together with a state transition function ( $Z \times U \rightarrow Z$ ) and the output function ( $Z \times U \rightarrow Y$ ). Several observations about this approach are relevant. First, the sets  $U$  and  $Z$  need not be disjoint. Second, the specification of  $Z$  and the state transition function is generally not unique. The state objects in  $Z$  are simply selected in such a way as to make the system "functional" in the sense described in (1). Third, no disturbance term has yet explicitly entered into the framework.

In theorizing about international relations, it has been suggested that it is possible to put more structure into the general "black box" view of systems by viewing foreign policy behavior from the perspective of "adaptive systems" (Rosenau, 1970, McGowan, 1970, Thorson, 1974). Such systems belong to the general class labelled by Simon as "artificial systems" and are characterized by being directed toward human goals. According to Simon (1969):

1. Artificial things are synthesized (though not always or usually with full forethought) by man.
2. Artificial things may imitate appearances in natural things while lacking, in one or many respects, the reality of the latter.
3. Artificial things may be characterized in terms of function, goals, adaptation.
4. Artificial things are often discussed, particularly when they are being designed, in terms of imperatives as well as descriptives [pp. 5-6].

An artificial system has a number of components or subsystems. There is an inner environment (I.E.) which is "attempting" to achieve goals in an outer or task environment (O.E.). The I.E. receives information about the O.E. through an observation

interface and send policies or behaviors into the O.E. through an access interface. Finally, in order to evaluate alternative policies (without actually implementing them) the I.E. must have a representation or "image" of the outer environment. The structure common to artificial systems is shown in figure 1.

For the purposes of this paper, the I.E. will be interpreted as being a national government and the O.E. as that which is external to the government (including objects from both "domestic" and "international" domains). The observation interface includes those aspects of the I.E. which are charged with monitoring the appearances of the O.E. while the access interface includes those aspects of the government responsible for getting policies into the O.E.. The "image" includes the governments long and short term images (to be explicated below) as well as various planning and forecasting components.

Prior to providing a simple illustration of these components several comments on this approach are in order. First this approach requires no "in principle" position on a unitary rational actor approach versus a bureaucratic/organizational approach (Allison, 1971; Halperin, 1974). While the course taken here is compatible with the organizational perspective, some of the arms race work (e.g., Brito, 1972) could be restructured into the artificial systems framework and, as such, would represent a unitary rational actor approach. Second, the use of the observation interface allows a clear distinction between the O.E. as it "really" is and the O.E. as filtered by the observation interface. Finally, care should be taken not to reify the objects in the artificial system. Objects believed to be in the world may be represented as being objects in more than one component. For example, the U.S. Wage and Price Control Board had the responsibility of monitoring wage and price levels (observation interface) as well as the responsibility to effect wage and price changes (access interface). Thus the Board can be assigned to both the access and observation interface.

An understanding of how the artificial systems components inter-relate can be enhanced by going through a simple example. Let the inner environment (I.E.) represent a country's economic policy bureaucracy and the outer environment (O.E.) represent the country's economy. Assume further that the bureaucracy's objective is to keep the economic system in a certain specified set of acceptable states. The state of the economy is then represented by the vector  $x$  and might include such things as each citizen's income, all sales transactions, and other such objects.

The officials must have some way of observing  $x$  so that they can determine whether the economy is in an acceptable state. However, they can not observe each and every sales transaction, etc., directly. In fact, even if all this information could be obtained, it would probably exceed their information processing capability. Therefore they must filter all of the minute economic information into

something manageable. This is the task of the observation interface and would include various agencies to collect and aggregate economic data. Since, in this example,  $x$  would contain far too much information, the observation interface might incorporate some sort of indicator system. Thus instead of having  $x$  as an output, the I.E. receives  $y$ . The vector  $y$  might include such indicators as GNP and unemployment rates. In some cases  $y$  and  $x$  will be equivalent. Most often, however, this will not be the case and the notation reflects this possible distinction.

Upon receiving  $y$ , the I.E. must evaluate it to determine what sort of policy is indicated. The results of this evaluation will depend in part upon I.E.'s image of the O.E. The image might for example, consist of a Brookings forecasting model of the economy. Generally, this image will, at least in part, contain the elements of  $y$ . In this way  $y$  can be used to set the "state" of the image and various policy alternatives ( $\bar{u}$ ) can be put into the image to access their differential impacts ( $\bar{y}$ ).

The elements of the  $u$  vector, to have any impact, must have some way of getting into the O.E.; that is, the I.E. must have some access interface which is capable of implementing  $u$  in the O.E. Fiscal and monetary policy might serve as accesses.

This very crude economic example hopefully makes more clear the basic components of an artificial system. In addition, it should serve to illustrate the high degree of inter-relation between the components. This example was not intended to suggest that the components of an artificial system will have simple "real" world interpretations. The distinction between the components is analytic and it may be that the vocabulary generally used in theorizing about governments is incapable of reflecting these distinctions. In using artificial systems concepts to construct empirically grounded theory, it may be necessary to develop some new terminology.

This overview, while superficial should provide clues to the systems framework which will be employed in this paper. Specifically, systems are viewed as set theoretic structures. Explicit acceptance of such a view makes it difficult for the theorist to fall into the trap of reifying systems. A system is something the theorist posits to stand in some relation to objects he believes to comprise (parts of) the world.

Further, the abstract notion of a system as a relation on the cartesian product of objects (i.e., sets of appearances), forces the theorist to specify the objects about which he is theorizing. All too often, especially in theories expressed in natural languages such as English, the tendency is to assume that "everyone knows" what is being theorized about. Since "everyone knows", there is no need to specify explicitly what objects make up that world. Yet, it can be argued that theories are not about the world but about "representations" of the world (or indeed, there may be many worlds), and it is useful to make public that representation by specifying

it as unambiguously as possible.

This specification can begin by writing down the objects (and their possible appearances) which populate the representation. It is completed when, in addition, the theoretically allowable conjunctions of appearances are specified. The fact that the set of logically possible conjunctions of appearances is greater than the set of theoretically allowable conjunctions is what gives structure to the world and allows scientific theorizing to be at all successful. Writing down the world being theorized about is equivalent (under the terminology of this paper) to specifying the system the theory is about.

## § 2 Complexity

The artificial systems framework discussed in the previous section is structurally very similar to a systems control problem. In control theoretic vocabulary the I.E. is the "control mechanism" and the O.E. is the "process" or "plant" being controlled. Arbib (1972) described a control problem as: "Given reasonably accurate descriptions of a system and some performance required of it, to find inputs which, when applied to the system, will elicit (a reasonable approximation to) the desired performance (p. 80)." Viewing a government as a control mechanism (which must be done if it is asserted to be "adaptive") does not require that it be considered an optimal control mechanism (i.e., that it produces "best" policies). Such a view does, however, allow the use of many control theoretic concepts in the development of theory.

Given a control perspective, there are several general sorts of questions the analyst might ask. First, for particular nations, what do the goals, inner and outer environments look like? Second, given an inner and outer environment, (that is holding the structure of the inner and outer environment fixed) how can certain goals be "best" achieved? And third, given some set of objectives, what sorts of inner and/or outer environments can "best" achieve them? These can be termed questions of description, policy, and design respectively. Elsewhere (Thorson, 1975) it is argued that these questions can be ordered in the sense that an answer to policy questions will generally require having fairly good answers to descriptive questions and that solutions to problems of political design will require prior work in the policy and descriptive areas. However, the focus of this paper will be essentially upon description. Description is being used in a very general fashion to refer to a standard concern in constructing scientific theory - accounting for observations, identifying interrelationships among them, and predicting new observations.

At its most abstract level, the descriptive problem is made difficult by the apparent complexity of the international system. Von Neumann (1966), for example, argued, "It is characteristic of objects of low complexity that it is easier to talk about the object than produce it and easier to predict its properties than to build it. But in complicated

parts of formal logic it is always one order of magnitude harder to tell what an object can do than to produce the object. The domain of validity of the question is of a higher type than the question itself." While the precise meaning of this passage may be unclear, Von Neumann seems to be suggesting that as systems get beyond some threshold level of complexity, modes of understanding them change. Shaw (1970) uses Von Neumann's statement to conclude that "any science, like psychology, which desires formal models of highly complex systems, like organisms, will have to consider Von Neumann's conjecture a threat to the fulfillment of its explanatory goals." Indeed, the claim is often heard that the relatively primitive state of the social sciences can be attributed to the complexity of the phenomena.

Given the prime-facia plausibility of the "argument from complexity," it will be useful to explicate somewhat more completely what might be understood by complexity in a systems context. Forrester (1969) defines complex systems as systems with "a high-order, multiple-loop, nonlinear feedback structure," and he argues that such systems behave very differently from the simple systems often encountered. Forrester's position is a special case of the more general view (Levins, 1970) that complex systems are systems with many objects and few constraints in the relations between the objects. As a simple example of the impact of the number of objects (i.e., variables), consider a social system with  $N$  objects. Object  $j$  in this system takes on the appearance  $N$  with probability  $1/N$  and the appearance 0 with probability  $1 - 1/N$ . As  $N$  gets very large, the expected appearance of object  $j$  goes to 1, yet the probability of ever observing  $j$  in an appearance other than 0 goes to 0. It is unlikely that even the most sophisticated empirical work would uncover object  $j$ , yet from say a policy standpoint the presence of  $j$  in the system, even at 0 value, may be of extreme importance in designing policies.

From examples such as these it is tempting to conclude that complexity is an "intrinsic" characteristic of a system. However, for a variety of reasons it appears that no adequate characterization of the complexity of a system can be given independent of the class of systems operating (or, in the sense employed here, controlling) with that system. The reason for this is that the structure of a "controlling" system can be so designed as to remove some of the "intuitive intrinsic complexity" from its environment. For example, many living species may well be facing a less complex environment now than they did thousands of years ago. Through evolution many of the common relational structures have been "preprogrammed" into the human brain. That is, the brain has developed in such a way as to operate extremely effectively in an environment of three dimensions, fast response time (the time it takes for the environment to respond to external stimuli), and few relevant variables. This preprogramming through evolution or design may well be a key to any system's behaving adaptively in a seemingly complex environment.

Baby salamanders, for example, live completely on land for a time after they are born before entering the water in search of new forms of food. Is their ability to swim learned in some fashion; perhaps by imitating other salamanders or by trial and error? Coghill (1929) anesthetized a salamander at birth and kept it in this condition for the length of time salamanders had been observed to remain on land before beginning to swim. After this time had elapsed, the salamander was dropped into water. Even though no learning could have taken place, the salamander was able to swim effectively. The reason for the delay between the time of birth and the onset of the ability to swim was that, as a part of the maturation process, a certain neural connection had to be made in the salamander's spinal cord. The ability to swim is preprogrammed into the developmental process of the salamander. The effect of dropping a one week old salamander into a pool of water would be very different from that of dropping a five month old salamander into the same pool. Does the complexity of the pool of water change if one animal is able to deal effectively with it while another is not? A more rigorous example drawn from automata theory might make this point more clearly. The problem is to design a Turing machine which can determine whether a string of symbols reads the same backwards as forwards (as in ABLE WAS I ERE I SAW ELBA). Arbib (1969) proves that, for a Turing machine with one reading head the time necessary to decide the problem increases with the square of the length of the symbol sequence. For a Turing machine with two reading heads, however, the time increases only as a linear function of the sequence length. If the complexity of the problem is indexed by the time required to solve it, it is clear that the internal structure of the "solving machine" must be specified rather carefully.

These examples lead to a conclusion similar to that of Nurmi (1974), "Complexity can be viewed as an ontological property of the relationship between the actor and the environment (p. 84)." As long as the focus of study is systems with control structures, complexity must be viewed in a contingent fashion. The next section will suggest implications of this contingent view for theorizing about control structures.

### § 3 Control Structures

Mention has been made of the similarity between an adaptive systems approach and a control theoretic perspective. If governments are to be convincingly modelled as control structures, it is important that the models be capable of exhibiting a similar range of behaviors as do the governments being modelled. For example, most governments are organized hierarchically, have multiple (sometimes conflicting) goals and exhibit "redundancy of potential control." While there are numerous other properties which might be predicted to governments, the above three are enough to greatly limit the class of admissible control structures. Since the first two of these have been treated in some detail elsewhere (Anderson, 1974; Phillips, 1974;



Thorson, 1974), only the "redundance" notion will be discussed here.

According to Arbib (1972, p. 17) the principle of redundancy of potential control "states, essentially, that command should pass to the region with the most important information." As an illustration Arbib (who attributes the example to Warren McCulloch) cites "a World War I naval fleet where the behavior of the whole fleet is controlled (at least temporarily) by the signals from whichever ship first sights the enemy, the point being that this ship need not be the flagship, in which command normally resides (p. 17)." The critical point here is that potential control need not reside in only one portion of a government. Indeed the way in which various governments resolve the redundancy is critical to understanding and explaining its behavior.

If it is accepted that governments are characterized by redundancy of potential control then very careful attention must be paid to how research questions about governmental behaviors are posed. In another context Newell (1973a) was critical of a view of science which holds that:

Science advances by playing twenty questions with nature. The proper tactic is to frame a general question, hopefully binary, that can be attacked experimentally. Having settled that bits-worth, one can proceed to the next. The policy appears optimal . . . Unfortunately the questions never seem to be really answered, the strategy does not seem to work (p. 290).

As an alternative, Newell proposes the development of "complete processing models." Such complete models of necessity include a specification of the entire control structure. Such a specification would seem especially appropriate in the face of control redundancy since studies focusing on only a portion of the control structure will generally fail to face the critical question of under what circumstances control passes from one location to another.

One way to begin to develop answers to these questions is to put more structure into the "image" component of the artificial system. In order for a government to respond adaptively to O.E. changes it is essential for there to be some sort of image of the O.E. This use of image is not meant to suggest the existence of a "picture" of the O.E. somewhere in the government archives. Rather, the concept is used abstractly to refer to that portion of the I.E. which "organizes" past O.E. behaviors and thereby uses new information to trigger responses. In this sense it is useful to distinguish two sorts of images. The first is a long term image (LTI) and includes representations of relatively invariant properties of the O.E. Within many bureaucracies rather formal standard operating procedures act as a LTI. More ambient or current information about the O.E. is stored in what might

be called the short-term image (STI). The contents of the STI is used in conjunction with the LTI to determine precedence of control within the I.E.

This distinction between the STI and the LTI leads very naturally to a particular way of modeling the control structure of the "complex" artificial system - that of production systems. A production system is a means of explicitly modelling redundancy of potential control. "It consists of a set of productions, each production consisting of a condition and an action (Newell, 1973b, p. 463)." Productions are rules stated in the form of a condition and an action: C→A. In our terms, the "condition" refers to the contents of the STI and the actions may involve policy changes (u) intended to lead to goal satisfaction or, more frequently to changes (transformations) on the STI. These changes involve modification (including deletions) of content of STI as well as addition of new content (which may appear externally as a switch in control. A more complete description of the rules governing production systems is provided by Klahr (1973):

- i. The productions are considered in sequence, starting with the first.
- ii. Each condition is compared with the current state of knowledge in the system, as represented by the symbols in (STI). If all of the elements in a condition can be matched with elements (in any order) in (STI), then the condition is satisfied.
- iii. If a condition is not satisfied, the next production rule in the ordered list of production rules is considered.
- iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).
- v. When a condition is satisfied, all those STI elements that were matched are moved to the front of STI.
- vi. Actions can change the state of goals, replace elements, apply operators, or add elements to STI.
- vii. The STI is a stack in which a new element appears at the top pushing all else in the stack down one position. Since STI is limited in size, elements may be lost.

(p. 528-529).

A substantive example of a rather simple (and very stylized) production system is provided in Figure 2.\*

The production system in Figure 2 is an attempt to describe the behavior of the Libyan Revolutionary Command Council. Recently Kaddafi was asked to step down from his political-diplomatic position

\* Paul Anderson and Michael Hainline assisted in the development of this example. A more complete description may be found in Anderson (1974).

but retain his position as Commander-in-Chief of the Libyan armed forces. The illustrative production system is an attempt to specify those conditions under which the Council will request that Kaddafi step down. This production system was built upon the assumption that the reasons that Kaddafi might be asked to step down reflect the perception on the part of the members of the Council that things are not going well for Libya. Some of the indicators picked up through the observation interface that the Council might consider are: fiscal irresponsibility, food shortages and excessive religious orthodoxy. It was also assumed that the Council was more willing to ignore some of the bad points (marks in the production system) if there were favorable aspects of the situation to off-set the marks. For example, if Sadat loses face, there is an increase in skilled labor, or if there is a food surplus (relatively), the council will overlook some of the bad points about Kaddafi's management. If it is the case that even with the good points, Kaddafi has managed to accumulate four marks, the Council will request his resignation. Initially the STI of the Council is filled with HIL or blank symbols. Since none of the first 15 productions will be satisfied, the sixteenth production, which contains no condition will be executed. The action READ means that the Council looks at the environment and takes a reading of the current state. As long as the symbol read from the environment does not invoke a production, the system will continue reading until one is found. Suppose the first "recognizable" symbol is a food shortage. After it is placed in the STI by the READ operation, production 5 will be executed. This results in FOOD SHORTAGE being marked as OLD. The OLD \*\* operator is a replacement that modifies the contents of the STI. After the matched symbols have been moved to the top of STI, the first symbol in STI is replaced by (OLD \*\*), where \*\* is replaced by the first symbol. This prevents the system from counting FOOD SHORTAGE twice, since FOOD SHORTAGE and (OLD FOOD SHORTAGE) are not the same. The production also results in a MARK being placed in STI. If at any time, Kaddafi has supported four radical foreign causes with no noticeable achievement, production 7 is executed, which results in all four supports of radical foreign causes being marked as old, and the addition of a MARK to the STI. If it happens that there is an increase in skilled labor when there is also a MARK in STI, both the skilled labor increase and the MARK are masked. In essence, one of the strikes is erased -- although it still takes up a position in the STI. If at any time, Kaddafi has managed to accumulate four MARKS, the symbol REQUEST will be placed in STI. This results in the Revolutionary Command Council asking Kaddafi for his resignation.

Notice that all of the productions that erase 'marks' from the STI are at the end of the system. This means that a mark can only be erased if there are no 'bad things' in the STI. If the set of productions that erased marks were to be moved to the top of the system, the chance for an erasure would be greater (and the chance for removal less). If production 3 were placed at the end, the only time that Kaddafi would be asked to step down would

be when neither anything good nor bad was happening. If it were inserted after production 11, the only time that he would be asked to resign is when he had accumulated four strikes, and at the present time all was going well, i.e., the short term memory was filled either with junk or positive symbols. Depending upon the sorts of things that the Council could be expected to receive from the environment, by rearranging the individual productions, the chance that Kaddafi would be requested to step down could be varied. Thus it is not enough to say that fiscal irresponsibility and food shortages count against Kaddafi in the eyes of the Council. One must be more specific about exactly what the conditions are that will cause the Council to request his removal.

Research is presently underway to develop more sophisticated sets of production systems for particular governments. The access interface is being modelled as receiving strings of symbols (x) from the O.E. and operating on these symbols. These operations then produce (y) for the STI of the various production systems comprising the I.E. Redundancy of control will be determined by the production systems in conjunction with the content of STI. Such a procedure allows multiple goals (conflicting or not) to be "considered." The goals are imbedded into the structure of the production systems and resolution of the redundancy question in effect "resolves" the problem of conflicting goals.

#### § 4 Conclusion

While the arguments presented in this paper do not really settle any substantive issues, they do suggest certain strategies for doing research - both theoretical and empirical - on the behavior of nations. First, explicit attention must be paid to the control structure of the government. Second, if the principle of "potential redundancy of control" is accepted then a "complete processing model" approach is indicated. That is, theories must be able to account for how redundancy is resolved. Research focusing only upon "sub-control" modules will not provide answers to this question. Third, such complete processing models may be too "complex" to provide useful analytic solutions. As Levins (1970) points out:

Suppose we did know the interrelations among all parts of a system and could describe the rate of change of each variable as a function of the others. Then we would have a very large set of simultaneous non-linear equations in a vast number of variables, and depending on so many parameters, the estimation of each of which may take a lifetime. . . . These equations will usually be insoluble. They would likely be too numerous to compute. If we could solve the equations the answer would be a complicated expression in the parameters that would have no meaning for us (p. 75).



Thus it may be necessary to rely upon computer simulations to provide a basis for experiments on control structures. Production systems are a possible mode of representing these control structures.

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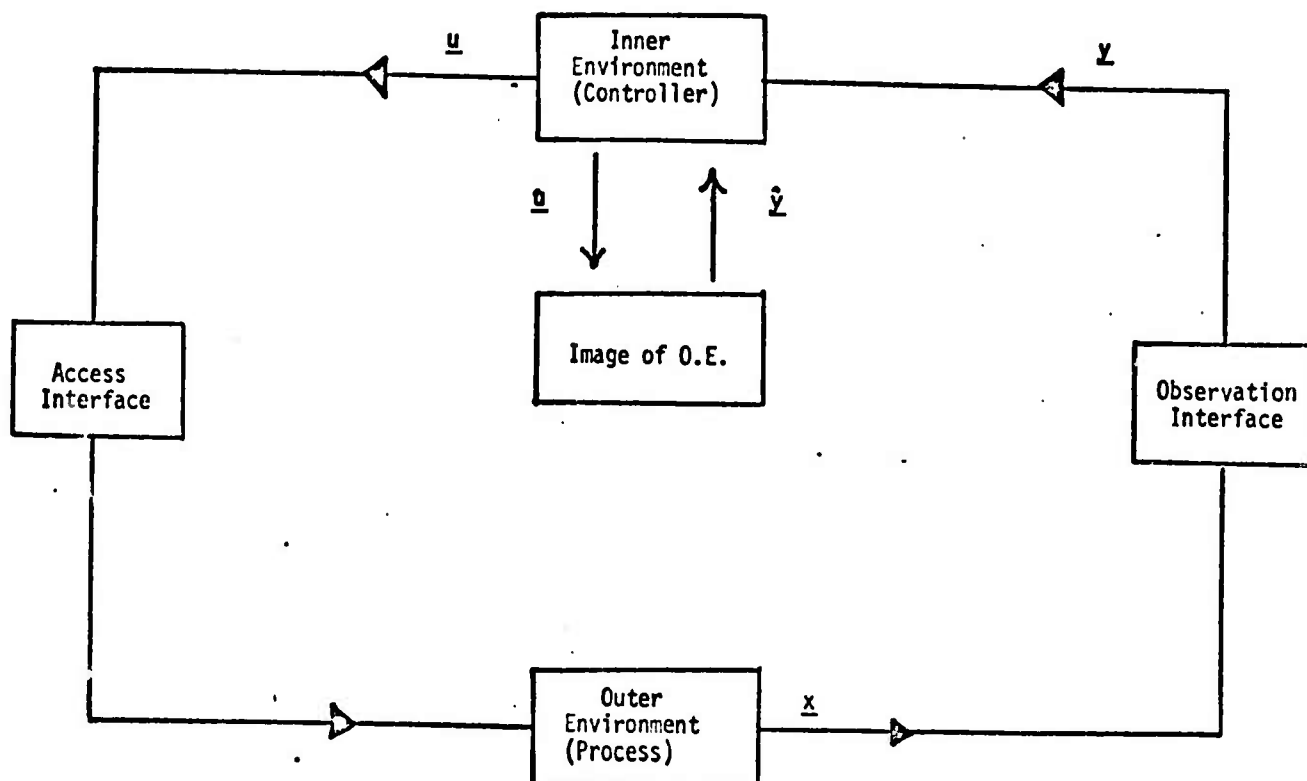


Figure 1 Artificial System Structure

PS: LRCC74

STI: (NIL NIL NIL NIL NIL NIL NIL NIL)

- 1: (STOP) → END
- 2: (REQUEST) → (OUTPUT "RESIGNATION", STOP)
- 3: (MARK, MARK, MARK, MARK) → (OLD(\*\*), REQUEST)
- 4: (FOOD SHORTAGE, FISCAL IRRESPONSIBILITY, NEGATIVE FOREIGN COMMENT BY AN ALLY) → (OLD(\*\*), REQUEST)
- 5: (FOOD SHORTAGE) → (OLD(\*\*), MARK)
- 6: (SUPPORT OF RADICAL FOREIGN CAUSES, NO ACHIEVEMENT) → (OLD(\*\*), MARK)
- 7: (SUPPORT OF RADICAL FOREIGN CAUSES, SFRC, SFRC, SFRC) → (OLD(\*\*), FISCAL IRRESPONSIBILITY)
- 8: (FISCAL IRRESPONSIBILITY) → (OLD(\*\*), MARK)
- 9: (NEGATIVE FOREIGN COMMENT BY AN ALLY) → (OLD(\*\*), MARK)
- 10: (BAN CIGARETTES or BAN ALCHOL or BAN LUXURIES) → (OLD(\*\*), ORTHODOXY)
- 11: (ORTHODOXY, ORTHODOXY, ORTHODOXY, ORTHODOXY) → (OLD(\*\*), MARK)
- 12: (FOOD SURPLUS, MARK) → (OLD(\*\*))
- 13: (SUPPORT RADICAL FOREIGN CAUSES, ACHIEVEMENT, MARK) → (OLD(\*\*))
- 14: (INCREASE IN SKILLED LABOR, MARK) → (OLD(\*\*))
- 15: (SADAT HAS TROUBLES, MARK) → (OLD(\*\*))
- 16: → READ

\* SFRC = SUPPORT OF RADICAL FOREIGN CAUSES

Figure 2 A Simplified Production System

The Role of Complete Processing Models in  
Theories of Inter-Nation Behavior \*

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## ABSTRACT

The Role of Complete Processing Models in  
Theories of Inter-Nation Behavior

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This paper falls into two portions. The nature of the scientific enterprise is considered in the first portion. The question is asked: Why does the field of international relations fail to exhibit the cumulative quality that characterizes a science? The reason for the lack of cumulativeness is argued to be the tendency to formulate research questions too narrowly. "Complete processing models" are offered as an alternative to the current style of theorizing. The role of computer simulations in this alternative theoretical style are briefly discussed. An illustration of this alternative approach comprises the second portion of the paper. After discussing the implications of modeling the national government as a goal seeking system, specific techniques and approaches to the simulation of a general goal seeking model are illustrated and discussed.

## The Role of Complete Processing Models:

### Diagnosis and Prognosis

Upon a reading of recent prefaces and other introductory remarks by scholars in the field of international relations, one is struck by a growing dissatisfaction in the field (Cf. among others, Jones and Singer, 1972; Wilkenfeld, 1973; McGowan and Shapiro, 1973; Alker and Bock, 1972; and Deutsch, 1973). What disturbs them is the fact that the cumulative quality of the scientific enterprise that we have all awaited with high expectations has failed to develop. The recurrent theme is: Why haven't we been able to put it all together? There are no bridges between our "islands of theories" (Cf. Guetzkow, 1950). For some the answer lies in the further identification of potent variables (Wilkenfeld, 1973). For others, it is in the communication of basic findings and propositions (Jones and Singer, 1972; McGowan and Shapiro; Alker and Bock, 1972). If we look around at our sister disciplines in the social sciences we find that our problem is not unique. We are not alone in our feelings of distress. In a recent paper, Allen Newell (1973a) wrestled with the same problem. He asked his colleagues in the field of psychology:

Suppose you had all those additional papers [that you will write until the time of your retirement], just like those of today (except being on new aspects of the problem), where will psychology then be? Will we have achieved a science of man adequate in power and commensurate with his complexity? And if so, how will this have happened via these papers that I have just granted you? Or will we be asking for yet another quota of papers in the next dollop of time? (p. 284).

In an attempt to come to grips with the somewhat disturbing question

he asked, Newell posed another question: Can you play 20 questions with nature and win? Beyond the field of psychology, it seems to me that the answer to this question has relevance for efforts at the explanation of the behavior of human systems from a small group to a nation and beyond. Newell's 20 questions game is a characterization of a strategy for doing science. This strategy is based upon the view that

[s]cience advances by playing twenty questions with nature. The proper tactic is to frame a general question, hopefully binary that can be attacked experimentally. Having settled that bits-worth, one can proceed to the next. The policy appears optimal--one never risks much, there is feedback from nature at every step, and progress is inevitable. Unfortunately, the questions never seem to really be answered, the strategy does not seem to work. (Newell, 1973a:290)

Instead of just accepting Newell's assessment of psychology as characterizing the field of international relations, it would seem prudent to see whether or not "20 Questions" is a popular game in IR, and whether or not it is working. Obviously, the first change in the rules of the game is that questions are rarely (Cf. Hermann, 1969; Robinson, Hermann, and Hermann, 1969) attacked experimentally. "Natural sources" of observations have been (and probably will continue to be) the mainstay of the discipline. Aggregate, content analytic, and events data manipulated with techniques ranging from the simple correlation coefficient to factor analysis and beyond are the basic tools of the discipline. But that difference is only cosmetic. The real question is: Do we use those tools to play 20 Questions? The hallmark of 20 Questions is the framing of a general question in a binary sort of way. Examples of the binary approach in psychology are: nature versus nurture or continuous versus all-or-none learning. Newell identified 24 of them.

While the explanation of the behavior of nations is still in its infancy compared to psychology there are several respects in which the field is patterned along a binary approach. Rosenau's (1966) 'pre-theory' has resulted in a number of binary oppositions based upon nation types (e.g., small versus large states) (East and Hermann, 1974; East, 1973). The study of crisis has resulted in several binary questions (crisis behavior versus noncrisis behavior, and certain aspects of crisis behavior itself) (Hermann, 1969; Robinson, et al., 1969; Holsti, 1965, among others). Are internal factors or external factors more potent for the explanation of the foreign policy behavior of nations (Rosenau and Hoggard, 1971; Rosenau and Ramsey, 1973)? Which is more important in foreign policy: the past behavior of a nation or the behavior of another nation (Tanter, 1972)? Probably the longest running session of 20 Questions involved the relationship between foreign and domestic conflict behavior (Rummel, 1963a, 1963b; Tanter, 1966; Wilkenfeld, 1968, 1969). It must be emphasized that there is no intention of disparaging the above cited works. They have all made significant contributions to the construction of Guetzkow's (1950) islands of theory. The question really is: Is it islands of theory that we need? I think not. Nor do we need the grand-sweep, macro-type theory for which Guetzkow's islands were an alternative. The problem with the large scale theorizing is that it lacks structure. When one attempts to take a theory based upon 'the' political system with its inputs, outputs, demands, and authoritative allocations and really use it, it turns out that much of the substance of the theoretical structure, the "stuff" that holds it together, is not there. What seemed at first glance to be a hard kernel was in reality too soft and pliable. Guetzkow's strategy for dealing with this problem was to develop middle

range theories. This strategy was based upon the view that the binding force missing in the grand style of theorizing could most efficiently be built as a bridge between specific and definite islands of theory. After almost twenty-five years of building, it seems we can't get off the islands. It turns out that Guetzkow's islands of theory strategy is another name for 20 Questions. And it seems in fact that we can't play 20 Questions with nature and win.

Newell approached the problem of the identification of this binding force between the islands in this way:

Suppose you know about an information processing system: its memories, its encodings, and its primitive operations (both tests and manipulations). What more would you require to obtain a complete picture? You need to know how the system organizes these primitives into an effective processing of its knowledge. This additional organization is called the control structure. (Newell, 1973b:464)

In more general terms, Newell's statement becomes: Suppose you have answers to all the binary questions you could put to nature. What more would you require to obtain a complete picture? The central point to Newell's argument is not that you can't play 20 Questions with nature. It is that you can't play 20 Questions with nature and win. Even if we knew that size made a difference, and that internal factors were more potent, and that for certain nation types there is a relationship between foreign and domestic conflict behavior, we still would not have a complete picture of the nation. We still would not have a science of nations "adequate in power and commensurate with their complexity." We would not know how these "facts" that we have discovered about a nation are organized to produce the behavior we observe. Newell terms this additional organization, the control structure. The control structure



specifies how all these facts about a nation fit together to produce behavior -- the system architecture. This notion of architecture can be made more explicit by taking a process view of a nation. (See Newell, 1973a and Thorson, 1975a for a further discussion.) Suppose that a nation is considered to be a decision making system. Further suppose that the decision process has been broken down into specific components or sub-processes, e.g., perception, information and alternative search, the influence of goals on choice, the choice process itself, and implementation. That knowledge alone is not enough to model a nation. You would have to know how those elementary processes are organized to form a whole. This organization is the control structure.

Newell's notion of control structure characterizes exactly what is missing in the field of international relations. That is the source of our discomfort. The grand stroke style of theorizing did not specify the control structure -- it was too abstract. Although it was hinted at in flow diagrams, e.g., Deutsch's (1966) communications model in The Nerves of Government. The island style of theorizing does not specify the control structure -- it is too specific. The grand island theorists wait for island builders to firm up their structure. The island builders wait for the grand theorists to build their bridges. Newell's solution to this dilemma is to stop waiting. He calls for his colleagues in psychology to build complete processing models rather than the partial models they now construct. A complete processing model (as its name would suggest) completely models the process. This notion of completeness can be illustrated as follows: Suppose that a nation is a decision making system. That is not a complete formulation. Too much is left unconstrained and unspecified. There are literally dozens of ways to

model the decision process, ranging from economic rationality to satisfying, or even a roulette wheel. Not all of these formulations will be descriptive of the way in which nations actually make decisions. Their control structures are different. A process model is made more complete when it specifies one of these ways for modeling the decision process. A complete processing model of the decision process has completely contained within itself the capability to generate decisions. Completeness should not be confused with truth. Completeness refers only to capability. The outputs from the model may not be correct. All that is required is that the model have the capability to produce outputs characteristic of the behavior of nations. By introducing the notion of the control structure, additional constraints are placed upon the complete processing model. Not only must the outputs be characteristic of national behavior -- so must the process by which they were generated.

This explicit modeling of the control structure through the specification of a complete processing model can best be illustrated by certain uses of the technique of computer simulation. The sort of computer simulation that best captures this notion is not merely a system of equations that describes the behavior of a nation. It goes beyond description into an investigation of the internal structure of a nation. This structural approach to simulation explicitly models the control structure. A linear model may very well describe the behavior of a nation. But in that case, the control structure is by default, linear algebra. In a complete processing model with an explicit attempt to model the control structure, the internal operations of the system are theoretically descriptive of nations -- not just the outputs. From the field of psychology, the efforts of Newell and Simon (1972) are examples

of control structure simulations. In their investigation of human problem solving, they have programmed a computer to prove theorems in elementary predicate calculus logic. They have programmed a computer to play chess. It is vitally crucial to note that these efforts are not simply technical displays of computer programming proficiency. Newell and Simon have attempted not to just program a computer to play chess -- but to play chess in the same manner as do humans. If one takes the decision making perspective on the behavior of nations, a complete processing model of a nation not only produces outputs that bear a strong resemblance to the decision outputs of nations, the model actually makes decision "in the same manner" as do nations. While the only examples of complete processing models with a sensitivity to the control structure are simulations in the style of Newell and Simon, that surely will not always be the case. But it does seem clear that until we have grown more accustomed to thinking in terms of control structures and complete processing models, the simulations of Newell and Simon will provide the exemplar. They serve as a convenient crutch to support this new strategy in theory building during its infancy.

As was mentioned above, the basic notion of a control structure has always been close to the surface in contemporary theorizing. The heuristic models consisting of boxes and arrows, information flows, and control are really very informal representations of the control structure, e.g., Figure I below. There are uses for heuristic models or conceptual frameworks. But one of them is not the representation of the control structure of a system. The modeling of control structures via complete processing models requires a much more rigorous and formal approach.

### A Strategy for the Construction of Complete Processing Models

Before outlining a strategy for the modeling of control structures via simulation, it should be emphasized that no matter how promising the notion of complete processing models may look, there is a great chance (if past experience holds true) that all of this will come to naught. The "long road to theory" is strewn with conceptualizations that have been tried and discarded. But it also must be remembered that it is through this process of conjectures and refutations that scientific knowledge grows (Popper, 1965).

There are two basic themes that will be used to develop this research strategy: 1) generative explanations; and 2) the role of computer simulations. In a generative explanation, it must be demonstrated how the behavior in question is generated (Holt and Turner, 1970; Simon, 1969). The strategy becomes one of design: What structures and processes will result in the production of the observed behavior? One has a potential generative explanation when one can exhibit a process that is sufficient to "mimic" the behavior in question. Thorson (1975b) calls these potential generative explanations, descriptive theories; Zeigler (1970) calls them behavior preserving morphisms; Newell and Simon (1965) call them sufficiency models. If it can be shown that the structures and processes are necessary and sufficient, one has a generative explanation. The process of moving from a position of sufficiency to one of necessity and sufficiency can be characterized by the concept of reduction. (Hanson, 1958) Initially, one starts with a model sufficient to mimic behavior. The behavior of this sufficiency model will generally have implications beyond the model in several respects. These implications will suggest new properties and behavior which should be true of

nations. These additional implications, plus the direct comparison between the behavior of the nation and the model provide the basis for further modifications of the model. It is at this point that the binary approach noted above can be used with greater confidence. But this use of a binary approach is not the game of 20 Questions. It is different in several respects: 1) There is a firm theoretical basis provided by the complete processing model; and 2) Since there is a basic model of the control structure, the choice of one or the other of the two alternatives will have other consequences for the behavior of the system. Under this approach, it is possible to use the whole of the theoretical structure in answering the question. (For a somewhat different formulation of this strategy, see Ackoff and Emery (1972), especially chapter 13.) The issue now becomes: How does one construct these sufficiency models? One strategy, illustrated in the later portions of this paper, is based upon the notion of organizing principles. By predicating certain properties of nations the class of admissible control structures is limited. These organizing principles restrict the class of systems which are considered to model the nation. For example, suppose that a nation is characterized as a goal seeking system. This initial predication means that any goal seeking system can be taken as a model for the government. Then by explicating those properties that must characterize the model for a nation, the class of admissible (or equivalent) systems is reduced. Governments have certain properties that set them apart from a general goal seeking system. Only certain types of goal seeking system exhibit the properties necessary for the modeling of a government. For example, some of the organizing principles developed below are that nations are multiple goal seeking systems, and that governments follow a satisficing,

decision procedure. In other words, any system taken as the model for a nation must be a multiple goal, satisficing, goal seeking system. In summary, this research/discovery strategy is based upon two question: 1) What must I assume to be true of a government if my model is to generate characteristic behavior; and 2) What can I not assume to characterize a government, given what I already know (or believe) to be true of a government. The first question illustrates the deductive nature of the enterprise. The second illustrates its inductive nature.

The other point, the use of simulation, plays a vital role in the strategy. Solutions come easiest when a question is well posed. Many past uses of simulation have been criticized on those grounds: Why simulate? You are using simulation as a way of generating deductions. If you had posed your problem correctly you could have an analytic solution. For many attempts at simulation, this criticism is justified. (Cf. Nordhaus' (1973) analytic solution of Forrester's (1971) World Dynamics simulation.) But it does not hold true for all uses of simulation. One response is that while it is true that simulations often represent attempts to deal with ill structured problems, the process of simulating defines those problems. In fact, Simon (1969) has argued that simulations are the ideal tool for increasing our understanding about such systems. In a sense, simulations tell us more about the system than we told the simulation about the system. In addition, Simon further argues that science is built from the roof down to the yet unconstructed foundations. This "top-down" approach works because the behavior of the system at one level depends on only a very abstracted and approximate characterization of the system on the next lower level. It is also the case that analytic solutions are not always appropriate.

For the types of problems that Newell and Simon (1972) consider, for the system that is developed later in this paper, and for generative explanations in general, the notion of an analytic solution in the traditional mathematical sense has no meaning. But the notion of a control structure does. In fact, one cannot simulate a complete processing model unless it is in fact complete in the sense of completeness used above. Is not that what is meant by a well posed problem in the first place? A problem posed completely and clearly, with no loose ends.

The remainder of this paper represents an illustration of the construction of a complete processing model of a nation. It falls into two parts: 1) the representation of a nation; and 2) the programming of that representation as a computer simulation. The perspective taken is that the nation is a goal seeking system. The next section takes this basic representation and further refines it through the process of equivalence classes of systems. The second portion is concerned with techniques and issues involved in the modeling of a complete processing model of a nation.

# The Nation as a Goal Seeking Decision System: A Representation

What does it mean to characterize a nation as a goal seeking system? Simply put, the predication of the property of goal seeking to a system means that the behavior exhibited by the system is the system's attempt to steer or control (Cf. Deutsch, 1966; Simon, 1969) its environment so as to achieve a set of goals. As was mentioned above, the research and discovery strategy used here is based upon the notion of equivalence classes. Through successive iterations the class of system to which the nation is posited to belong to is refined. This refinement is essentially the identification of properties which are held to be true of nations but not of the general class of goal seeking systems. By simply including the nation as a member of the class of goal seeking systems there is the implicit statement that a servo mechanism and a nation are alike in all significant respects. There are several reasons why a nation cannot be considered equivalent to a servo mechanism. The purpose of this section is to identify and explicate those reasons.

The basic components of the adaptive goal seeking framework

----- FIGURE I ABOUT HERE -----

are: 1) the inner environment (IE); 2) the outer environment (OE); 3) the access interface (AI); 4) the observation interface (OI); and 5) the model (or image) of the OE (M). (Cf. Bailey and Holt, 1971; Simon, 1969; Thorson, 1974) The interpretation of this framework into national decision system terms results in the following names being assigned the basic components: 1) the inner environment is the government of a particular nation; 2) the outer environment consists of everything that is external to the governmental structure of the IE; 3) the observation interface are those portions of the government that are



responsible for the observation of the current state of the OE; 4) the access interface is composed of those components of the bureaucracy that are responsible for executing the actions that flow from the IE; and 5) the model is a shorthand term referring to how the various elements in the national bureaucracy responsible for the determination of decisions believe the OE works. It is important to note that the IE is defined strictly as the government. (For the purposes of this paper, we will only be concerned with the decision making aspects of the IE. The term decision mechanism represents those aspects.) In contemporary theorizing in the field of international relations it is often the case that the unit of analysis is the nation, often expressed as the "political system." This view is best exemplified by the efforts of Rummel's (1971) status field theory or Singer's (1972) Correlates of War Project. It is not claimed that the approach advocated here is strictly better than the specification of the unit of analysis as the nation. But given the types of concerns expressed and the sort of explanation and theoretical structure desired, the specification of the IE as the government seems more useful than the specification of the IE as the nation. On the other hand, there are instances where it may be more efficient to view the unit of analysis as the nation as a whole. Note that taking the government as the unit of analysis does not imply that a choice has been made between the unitary actor or bureaucratic/organizational (Cf. Allison, 1971; and Allison and Halperin, 1972) representations of the government. Both are consistent with the adaptive framework. While the work reported here does view the government as composed of several organizational actors the concepts developed are not restricted to a bureaucratic/organizational viewpoint. The second aspect that deserves

mention is the definition of the outer environment as everything external to the IE. This distinction is captured to a certain extent in Singer's (1961) discussion of the notion of levels of analysis. While this approach is a systems approach, it is not a systemic approach as characterized by Easton (1953), Kaplan (1957) or Parsons (1958). While part of the OE would, in current international relations parlance be called the international system, this is not the same international system of which Kaplan et. al. speak. The system is the national government. What is called the international system portion of the OE is Kaplan's international system, minus the nation under study. What is called the domestic political system in Easton's terms is also included in the OE in the same manner as Kaplan's system is included. There is not a priori distinction between domestic and foreign environments. While it is the case that in some ultimate sense everything external to the nation is part of the OE, considerable simplification of the size, complexity, and extent of the OE is possible. (See Simon (1969) for a discussion of the architecture of complexity.) From the perspective of the system, the model (M) of the OE will specify the causally relevant linkages. The final comment concerns the nature of the observation and access interfaces (OI and AI). Both the OI and AI are part of the IE, i.e., they are portions of the national governmental structure. Because they perform distinct sorts of functions (exhibit different classes of behavior) they represent separable components. But the access and observation interfaces themselves need not be distinct organizational members of the national governmental bureaucracy. Consider the Wage and Price Control Board. It had the responsibility of monitoring wage and price levels (observation) and it had the power to control wage and

price changes (access). But because there were two classes of behavior that the Board could exhibit (observation and control) the functions of the Board can be assigned to both the AI and OI.

At a basic level the system operates as follows: The national decision system has a set of goals for the configuration of the OE. Under the control of the decision mechanism, the OI takes observations on the OE and sends that information to the decision mechanism. The decision mechanism then compares the image it receives of the OE with the goal state. Based upon the perceived discrepancies between the goal state of the OE and the perceived state of the OE, the decision mechanism begins to search for behaviors it could emit to move the OE closer to the goal state. The decision mechanism uses its causal model of the OE to assess the degree to which a given behavior or set of behaviors will increase the level of goal attainment. When the decision mechanism discovers a set of behaviors it deems acceptable, it instructs the AI to emit those behaviors. Because of the manner in which the decision system uses its causal model, both the behavior and structure of the OI and AI are affected by the content of the model. The OI will only be sensitive to those features of the environment the M has identified as important. The behavior of the AI will obviously depend to a great deal upon the content of the M (in addition to the search procedure and the acceptability criteria used by the decision mechanism). The M will influence the behaviors the AI will emit and the sorts of behaviors the AI must have the capability of emitting. The behavior of the system is an endless loop: perceive, compare, decide, react, perceive, ..., et cetera.

The basic process has been explicated. Now the operation of the system will be examined more closely for the purposes of 1) putting some constraints on the operation of the various components; 2) highlighting the effect of those constraints on the operation of the system as a whole; and 3) increasing the specificity of the sub-class of goal seeking systems to which the nation belongs.

While it is known that the operation of the OI and the AI are by no means unproblematical -- the bureaucratic politics "paradigm" (Allison, 1971; Allison and Halperin, 1972) is centrally concerned with the contingent character of these processes -- it simplifies the discussion greatly to make this assumption. Since we have made these simplifying assumptions about the nature of the interfaces, we are now in a position to begin talking about the decision process and the role of environmental images or models in the operation of the decision mechanism. There are three steps in the operation of the system yet to be specified: 1) A comparison of the degree of difference between the observed and goal environments; 2) The use of the decision mechanism's image of the environment to "predict" changes in the environmental state as a function of the behavior of the AI's; and 3) A choice of AI actions based upon some sort of "maximization" criteria applied to goal achievement.

We really aren't sure what calculus decision makers use in determining goal achievement. Common sense would indicate that the decision mechanism is not physically capable of considering all goals at the same time. In fact it could be argued that the OI is only capable of scanning a proper subset of the variables the decision mechanism would like to scan. Since the system cannot be equally cognizant of all goals and their associated environmental indicators, at any given point in time

the decision mechanism must in some manner select those goals to which it will be attentive. The question becomes: By what process are certain goals selected for more attention than others? Notice that for a simple decision mechanism, a servo mechanism for example, there is only one goal. In this case the process of goal attentiveness or the definition of a preference ordering of all environmental states is straight forward. Consider a servo mechanism attached to the motor of a phonograph turntable. The goal is a rotation speed of  $33 \frac{1}{3}$  revolutions per minute. The environmental state is the actual speed of the rotation. The servo mechanism can easily define a preference ordering over all environmental states. To further simplify the example let us suppose that the mechanism finds any speed other than  $33 \frac{1}{3}$  revolutions per minute equally undesirable. The system finds the decision as to which environmental variables to monitor and which goal to be attentive to unproblematical. The servo mechanism has the task of monitoring the speed of the rotation of the turntable (or some analog of it) and adjusting the speed accordingly. In a situation where the system is faced with two or more goals, it must somehow determine a preference ordering over all of the possible environmental states. Consider the case of a person in the midst of an energy shortage. The individual has two goals -- save energy and maintain a certain level of comfort. (The fact that these goals can be considered mutually exclusive makes the point clearer but does not imply that this relationship holds only in the case of mutually exclusive goals.) The issue the individual must face is whether saving energy or staying warm is more important. Is the dissatisfaction greater when the room is cooler than desired, but more energy is being saved -- or when the room is comfortable, but energy is

not being conserved? The question is not merely so simple as it was when there was only one goal.

Even though the problems outlined above have not been solved, let us assume that some suitable preference ordering over all environmental states has been achieved, i.e., we know how the decision mechanism evaluates the various possible mixes of environmental states. The next topic that will be considered will be how the decision mechanism "decides" what is the "best" way to decrease goal dissatisfaction. The major assumption or observation about the ability of humans to make decisions that is crucial to this element of the process is: humans do not have the capacity to consider all of the possible variables they could manipulate; they do not have sufficient information at their disposal to accomplish the task, even if they had the power to do so; and finally since a decision mechanism must depend upon its fallible model of how the OE works, even if it had all of the information and the ability to process it, the decision mechanism does not know enough about how the world works to make a "best" choice. One of the first to recognize that humans were not the "all powerful and rational beings" that much of decision theory held them to be, was Herbert Simon. Simon (1955) introduced the notions of satisficing and bounded rationality as descriptions of how men really behaved. Under Simon's conception of the decision process, decision makers did not search until they found the optimal solution, but rather they looked until they found one that they thought was good enough. Once they found a solution that satisfied their minimum criteria of acceptance they stopped looking. This notion of the decision process seems very close to the manner in which decision makers seem to behave. Using this satisficing notion for the basis of the operation of



the search and decision procedure, there are two basic interpretations that can be used as the basis for a decision algorithm. The first is that the decision mechanism searches for alternatives to the current policy mixture only if the dissatisfaction is above the satisficing limit. The second is that the decision mechanism always searches for alternatives when there is any degree of goal dissatisfaction. Using this representation, the decision mechanism always searches. But if the goal achievement is below the satisficing threshold, the search for alternatives will be more encompassing and further reaching. These two basic search and selection algorithms use the notion of an absolute satisficing limit. They can both be reinterpreted in a relative sort of frame of reference. Thus the satisficing limit might be: Decrease the current dissatisfaction by 30%. The decision mechanism would search for a relative increase in goal achievement rather than an absolute level. Regardless of which of the four procedures are used as the basis for the algorithm, the system must have some sort of time or length of search limit. The time limit criteria is needed for those cases when the decision mechanism is unable to locate a set of inputs that would be expected to bring the goal achievement up to some acceptable level. Since it is assumed that there is some urgency associated with the decision process, the decision mechanism must produce some outputs. When the time or length of search limit has been reached, the decision mechanism will take the best alternative it has uncovered up to that point and use it, hoping to find something better next time.

Once the decision mechanism has decided whether or not it is going to search, and how broadly it is going to search, the decision mechanism is faced with finding a set of outputs that will increase the current

level of goal achievement. The decision mechanism searches for sets of output values for the variables that it "thinks" are important and checks, by means of its model, whether or not it can be reasonably expected the outputs will achieve their intended consequences. In effect the system generates the expectations of what the OE will be sending it on the next decision cycle, contingent upon that particular set of inputs being applied to the OE. If the proposed solution takes (or at any rate the decision mechanism thinks it takes) it further away from its goal, the decision mechanism will try a different route. On the other hand, if the mechanism perceives that a particular class of the manipulable variables is taking it closer to its goal, it will continue search in that same direction. Since the model is not perfect it will make mistakes. One would expect that since the decision mechanism has some idea of how the world works, its search for variable values would not proceed in an entirely random basis. Derived from the model and experience would be some expectations as to the effects of various outputs on the behavior of the OE. It would be expected that the decision makers would use these expectations as a guide in their search. It will not always be the case that the decision mechanism proceeds in a totally "rational" fashion. If the basic model that the mechanism uses to "think" about the OE is bad, inconsistent, or largely unspecified, the search behavior would be expected to be influenced accordingly. Another factor that would influence the pattern of search behavior would be the complexity of the conceptual model. A model, fairly complex and sensitive to the various inputs the decision maker can feed it, would be expected to result in a very different pattern of search behavior than would a model based upon some very gross and crude



notions about how the world works. As was mentioned above, the decision maker will continue searching until either one of two things happen: 1) A proposed input mixture brings the goal satisfaction below some level; or 2) Some sort of time or length of search limit has been reached.

It is important to note that at the beginning, this discussion considered a government as a member of the class of goal seeking systems. While the government is still considered to be a goal seeking system, several properties of governments set them apart from the general class of goal seeking systems. The government is a member of the class of goal seeking systems that have these additional properties: 1) They are multiple goal seeking systems; 2) They operate under one of the satisfying search and selection algorithms; and 3) They react to a perceived environment. As was noted above, this search for equivalence classes through the explication of the control structure is central to the process of discovery used here. While a fair amount of the control structure for national goal seeking decision systems has been identified up to this point, there are several aspects of the operation of the system that have not been discussed. Probably the most important of which are the notions of learning or the internalization of past experience, the structure of the causal model of the OE, the manner in which the decision mechanism internally represents its knowledge about the OE, the manner in which the AI and OI interact with the OE, and the process of perception. In addition, the bureaucratic aspects of the operation of the decision mechanism have not been dealt with. Instead of continuing the discussion of the aspects comprising the control structure of a government modeled as a goal seeking system, the discussion will now turn to consider techniques and approaches to the realization of the system and its control structure as a set of rules -- a computer program.

### The Realization of the Control Structure

At first it might seem that this shift in emphasis from a discussion of the control structure to a specification of the control structure is inappropriate. There are several reasons why this is not the case. The primary reason rests upon the relationship between the explication of the control structure and its realization, a computer program. In rough terms, a representation is a conceptual model. A realization is a computer program. To help illustrate this relationship, consider another type of representation of the nation, Richardson's (1960) arms race models. In the case of Richardson's differential equation model of the nation, the representation is the realization. The behavior of the nation in Richardson's case is represented as a differential equation. That representation can be directly manipulated. No additional translation of the representation is required before it can be manipulated, i.e., produce implications. In the present case the representation (the government as a goal seeking system) and the realization (a computer program that behaves like a goal seeking system) are not the same. One cannot directly manipulate the notion of a goal seeking system. Because the representation is not directly manipulable and because the realization of the representation is crucially dependent upon the control structure, the specification of the system in terms of a computer program turns out to be almost as theoretically relevant as is that which is represented. In other words, how the system is represented becomes a theoretically important question. It is often the case that the implications of the relationship between representation and realization are, if not ignored, at least not fully discussed. When mathematical tools are used for the manipulation of symbols, invariably certain simplifying

assumptions are used to aid in the analysis. The stipulation that certain relationships are in a specific form (e.g., a quadratic or linear function) or the assumption of certain properties (e.g., a normal distribution or interval level measurement) are all assumptions that are dictated by the mathematical structure. They are assumptions made for the purposes of expediting mathematical manipulations. Bush and Mosteller (1955:46) provide a typical example:

The form of these operators is dictated chiefly by mathematical considerations -- linear operators are chosen in order to make the theory more manageable.

When one is concerned with modeling the control structure via complete processing models, the form of the operators becomes a theoretically important question. Since the form of the operators is a theoretical statement, they should not be dictated chiefly by mathematical considerations. By making the realization just as important as the representation (from a theoretical perspective) they both must be considered at the same time. They cannot be separated. One portion of a theory cannot be closed, with the expectation that the other arbitrary portion to fall meekly and consistently in line. There are crucial interdependencies at work. It is with a sensitivity to these interdependencies that we now turn to a consideration of the techniques for the realization of the control structure as a computer program. The approach is composed of two related notions: 1) a structure for expressing the process models; and 2) the role of a language in the behavior of the system.

Production Systems: A Theory and Language for Process Models

Allen Newell has stated in another context that in order to "predict [the behavior of] a subject you must know: (1) his goals; (2) the structure of the task environment; and (3) the invariant structure of his processing mechanisms." (Newell 1973a:293) The notion of goals has been discussed previously. The structure of the task environment is identical to the manner in which the system perceives the environment it is attempting to control. Production systems represent a means for expressing the third element in Newell's list--the structure of the processing mechanism (the control structure).

Production systems represent a form for describing processing models -- a theory laden programming structure. Production systems explicitly incorporate theoretical assumptions, and provide a means of expressing the control structure explicitly. In fact they force one to be explicit about the control structure by making it an integral part of the specification of the process. Production systems have been used extensively in psychology (Newell, 1973b, 1966; Newell and Simon, 1972) for the expression of theories of human problem solving.

From a practical programming point of view, there are several programming languages which could serve as the basis for the specification. But as will be developed below, a production system is a very simple, yet very powerful structure. Much more so than, say FORTRAN. More importantly, production systems themselves are a control structure. (See Newell, 1973a) No attempt is made here to defend production systems against other possible formulations of a control structure. Production system do allow very natural interpretations of the control structure of a government. Production systems make a theoretical statement -- FORTRAN can make no such claims.

Processing models written as production systems are formed by a collection of independent rules, called productions. The rules (or productions) are stated in the form of a condition and an action:  $C \rightarrow A$ . The condition refers to the symbols in the short-term image (STI) of the system. The STI represents the system's transient image of the current state of the OE. The actions of the productions consists of transformations on the STI "including the generation, interpretation, and satisfaction of goals, modification of existing elements, and addition of new ones." (Klahr, 1973:528) A production system obeys simple operating rules:

- i. The productions are considered in sequence, starting with the first.
- ii. Each condition is compared with the current state of knowledge in the system, as represented by the symbols in STI. If all of the elements in a condition can be matched with elements (in any order) in STI, then the condition is satisfied.
- iii. If a condition is not satisfied, the next production rule the ordered list of production rules is considered.
- iv. If a condition is satisfied, the actions to the right of the arrow are taken. Then the production system is reentered from the top (Step i).
- v. When a condition is satisfied, all those STI elements that were matched are moved to the front of STI.
- vi. Actions can change the state of goals, replace elements, apply operators, or add elements to STI.
- vii. The STI is a stack in which a new element appears at the top pushing all else in the stack down one position. Since STI is limited in size, elements may be lost. (from Klahr 1973:528-29)

While a production system may appear to be deceptively simple (if not simplistic), there is a reservoir of analytic power underlying that simple structure. Post (1943) has proven that any Turing machine (a very powerful and abstract computer) can be modeled as a production system. But even more importantly, there is a one-to-one correspondence between the elements of a Turing machine and a production system. Thus it may

be possible by reformulating the production system as a Turing machine quintuple to use the analytic structure upon which Turing machines are built as an additional means of exploring the implications of the model.

The illustrative production system in Figure II is a highly stylized

-----INSERT FIGURE II ABOUT HERE-----

system that attempts to describe the behavior of the Libyan Revolutionary Command Council. (Although it should be noted that in terms of complexity and the resolution of the issues raised in this paper, the system in Figure II bears about as much resemblance to our goal as a flowchart for making fudge resembles a program.) Recently Kaddafi was asked to step down from his political-diplomatic position but retain his position as Commander-in-Chief of the Libyan armed forces. The example production system is an attempt to specify those conditions under which the Council will request that Kaddafi step down (or go to the desert for meditation). This production system was built upon the assumption that the reasons Kaddafi was asked to step down amount to the perception on the part of the members of the Council that things are not going well for Libya. Some of the indicators or monitor variables that the Council might consider are: fiscal irresponsibility, food shortages, excessive religious orthodoxy. It was also assumed that the Council was more willing to ignore some of the bad points if there were favorable aspects of the situation to offset the bad points (or as they are expressed in the production system, marks). Thus if Sadat loses face, there is an increase in skilled labor, or if there is a food surplus (relatively), the council will overlook some of the bad points about Kaddafi's management. If it is the case that even with the good points, Kaddafi has



managed to accumulate four marks, the Council will request his resignation. The actual operation of the production system is as follows: Initially the STI of the Council is filled with NIL or blank symbols. Since none of the first 15 productions will be satisfied, the sixteenth production, which contains no condition is satisfied. The action READ means that the Council looks at the environment and takes a reading of the current state. As long as the symbols read from the environment does not invoke a production, the system will continue reading until one is found. Let us say that the first "recognizable" symbol is a food shortage. After it is placed in the STI by the READ operation, production 5 will be executed. This results in FOOD SHORTAGE being marked as OLD. The OLD(\*\*) operator is a replacement or masking operation. The application of OLD(\*\*) to the symbol \$\$\$, results in \$\$\$ being replaced by OLD(\$\$\$) in the STI. OLD(\*\*) operates on the symbols of the conditional portion of a production. This prevents the system from counting FOOD SHORTAGE twice, since FOOD SHORTAGE and OLD(FOOD SHORTAGE) are not the same. The production also results in a MARK being placed in STI. If at any time, Kaddafi has supported four radical foreign causes with no noticable achievement, production 7 is executed, which results in all four supports of radical foreign causes being marked as old, and the addition of a MARK to the STI. If it happens that there is an increase in skilled labor when there is also a MARK in STI, both the skilled labor increase and the MARK are masked. In essence, one of the strikes is erased although it still takes up a position in the STI. If at any time, Kaddafi has managed to accumulate four MARKS, the symbol REQUEST will be placed in STI. This results in the Revolutionary Command Council asking Kaddafi for his resignation.

One of the striking things about production systems is that the order in which the productions are ordered has very real consequences for the operation of the system. Notice that all of the productions that erase 'marks' from the STI are at the end of the system. This means that a mark can only be erased if there are no 'bad things' in the STI. If the set of productions that erased marks were to be moved to the top of the system, the chance for an erasure would be greater (and the chance for removal less). If production 3 were placed at the end, the only time that Kaddafi would be asked to step down would be when neither anything good nor bad was happening. If it were inserted after production 11, the only time that he would be asked to go the desert is when he had accumulated four strikes, and at the present time all was going well, i.e., the short-term image was filled either with junk or positive symbols. Depending upon the sorts of things that the Council could be expected to receive from the environment, by rearranging the individual productions, the chance that Kaddafi would be requested to step down could be varied. Thus it is not enough to say that fiscal irresponsibility and food shortages count against Kaddafi in the eyes of the Council. One must be more specific about exactly what the conditions are that will cause the Council to request his removal.

As an example of a production system with more theoretical interest, consider the example in Figure III. This illustration is a portion of

-----INSERT FIGURE III ABOUT HERE-----

a larger production system that attempts to model the behavior of the Ministry of Agriculture of Saudi Arabia. The portion of the system illustrated here is concerned with the relationship between land and labor productivity (information from the observation interface) and



allocations of land, labor, mechanization, fertilizer, and irrigation water (actions of the access interface). This portion of the production system results in the generation of general policy guidelines. These general policy recommendations serve as inputs to another portion of the system responsible for translating these general directives into specific levels of fertilizer, etc. It is worth noting that the conditional portions of the production system (low labor productivity, for example) are not represented in the system as a number -- they are linguistic expressions. The observation interface generates a sentence describing a quality of the OE. The production system operates upon that sentence (as well as the specific level the linguistic expression represents) in the generation of a decision. This linguistic aspect of the system will be discussed in more detail below.

This completes the general discussion of production systems. Before proceeding with the discussion of the role of language and the notion of a grammar, there are several aspects of the specification that deserve note. Since production systems are being used for the realization of a government, the capabilities of the production system must be characteristic of the capabilities of a government. Among other things this implies that: 1) The production system have the capability to perceive and misperceive the current state of the OE; 2) The production system must take incoming messages from the environment and interpret them according to the beliefs, presumptions, presuppositions, and biases peculiar to the decision makers in a given country; 3) The production system must have the capability to rewrite the goals of the system; 4) The production system must have the capability to change the perceptual coding rules; 5) The production system should invoke a cognitive map or

image of the environment in its attempts to determine appropriate actions;  
and 6) The total production system should be modeled to reflect the  
bureaucratic/organizational aspects of the decision process. In short,  
the production system must have the capability to make decisions.

### The Role of Language and a Grammar

When we communicate with another person or a computer we do so by using a set of symbols that we both are able to perceive. In addition, only certain strings of those symbols make sense (or convey the intended meaning). We can't communicate with a computer by shouting at it, since it cannot perceive our attempts to communicate. In addition we can't tell it just anything, since it has the capability of making sense out of very specific strings of special symbols. The system that we use to communicate with is called a language, the symbols are elements of the alphabet of that language, and the rules for forming possibly intelligible strings of symbols is called a grammar. The grammar will not insure that the meaning that was intended is actually conveyed, since others can misinterpret what we had intended. In addition, grammatical sentences can have absolutely no meaning what so ever. The sentence: "Colorless green dreams sleep furiously." (Chomsky, 1957) might be considered a grammatical sentence but it conveys no meaning.

Since nations communicate with each other, any complete processing model of a nation must also include this capability. Using these notions of language and grammar, a language could be used for the communication of the behavior of the national decision systems. Governments would communicate with each other by sending sentences in a language. The output from the simulation would be a list of sentences. For example: Since Israel cannot resist Egypt if Israel is not resupplied, the U.S. will resupply Israel. The Arabs could respond by saying: We will not provide the U.S. with oil because of its resupply of Israel. A language could serve as a medium for communications within a government: If we do not give the U.S. oil, it will not encourage Israeli aggression.

These notions of grammar and language are really not as alien to the field of international relations as first might be imagined. One of the main sources or types of data that has been used in the field is events data. (McClelland and Young 1969; Hermann et. al., 1974; Burgess and Lawton, 1972). Events are actions by national decision systems, and events data simply represents the coding of these actions a single coding scheme, generally of the form: action, actor, target. Language is a coding scheme. It is the representation (coding) of meaning according to a set of rules (a grammar).

This approach to the representation of action differs from the standard events data approach in two respects. The first difference is in the level of detail (the information content of the event). A common event coding category is official diplomatic protest. While there has been some effort to also include in the coding scheme the context of the protest, in all cases almost all of the actual content (what the protest was about) has not been coded for analysis purposes. While it is possible to conceive of situations in which one could make sense out of correlations between event type categories, it seems virtually impossible to begin to build a process model of international relations in which the only means of communication between the various national bureaucracies is by contentless statements. In order to go beyond the type of theorizing that says: if a nation receives a diplomatic protest it will respond with an unofficial warning and an armed force mobilization, exercise and/or display (to use two of the categories from WEIS), a different sort of language will be required. That language must have content (meaning) as well as form (the type of action). Since the assumption that governments are goal seeking systems is taken seriously, it is imperative

that the language that governments "talk" with be able to express the goals of the decision makers. While Callahan's (1974) analysis of the goals of the five oil producing nations identified a wide range of goals, none of the goals he identified were of the form: "Decrease the number of formal diplomatic protests by three-fourths." A language is needed that is capable of expressing a much richer content than any of the existing event category schemes are capable of providing.

The second difference between typical events coding and this language building effort stems primarily from the assumption that nations perceive incoming messages within the context that they are generated. The standard approach followed by all existing events data efforts is the use of the coding category for the interpretation of actions. There is an explicit attempt to make perceptual decisions. Common categories include threats, accusations, and rewards. Since nations operate on a perceived OE, the perception of the meaning of the actions must be the responsibility of the decision system. What is a negative deed from the perspective of one nation may be a very desirable action as far as some other nation is concerned. This perceptual role in the standard approach to the recording of international interactions is handled by the coders, who are assigned the responsibility of making the distinction between a threat and a promise. (A threat is really nothing more than a promise with a negative consequence.) The simulated governments must make that distinction.

If the language is to be a neutral affair intended only for the transmission of ideas and not predetermined perceptions by some third party, the language must be structured so as to avoid the gross preprocessed perceptual categories of the standard events data approach. This

implies that the basic units of the language should be statements of action rather than perceptual categories. It will then be up to the perceptual portion of the decision system to parse the action message into its own cognitive map or conceptual categories. This is not to say that the word "threat" cannot appear in the language, but that it will be the job of the decision system to determine whether an action really is a threat, the consequences the action will have on the goals for the system, as well as the credibility of the action. This conception of the role of the language has some implications for the structure of the language, the second distinction between events coding schemes this approach. The manner in which "events people" have approached the structure of their coding categories is to devise a mutually exclusive and collectively exhaustive typology for the classification of international interactions. In essence they have listed all of the possible sentences in their language. They then look at the event or interaction and determine which of the sentential forms fits the action. This approach differs from the event approach in that rules for generating sentences in the language are specified rather than listing each possible sentence individually. If one has a small language consisting of only a few sentences, the list approach has some merit. On the other hand, if the language is large and capable of expressing a wide variety of sentences, some of which may be appropriate only in certain circumstances, the exhaustive listing of all sentences may be impossible. Imagine this situation: Suppose you are a proofreader, and it is your responsibility to insure that this paper contains only grammatical sentences. Further suppose that you have no knowledge of the grammar of the English language. Your only means for determining if a sentence is grammatical is to

look it up in a book that purports to contain all possible grammatical sentences. Now imagine that you have a set of rules for determining the correctness of a sentence. With those rules (the grammar) the job is vastly simplified. The way that formal linguists generally express it is that a grammar is the set of rules specifying admissible manipulations (stringing together) of the words of language. By taking a finite set of words and a finite set of rules, it is possible to generate an infinite number of sentences. The advantages of listing the rules over listing all possible sentences is substantial. By basing the language on a modest set of objects (actions and actors) and on a small set of rules, a rich language can efficiently be specified. A language of greater precision, breadth, depth, complexity, and richness than could be hoped to listing all possible sentences. It will result in a more complex, conceptually leaner, and theoretically powerful system for expressing the behavior of a nation than an event coding typology could ever hope to generate.

Very large demands are being placed upon the language. It must be able to describe a context that will allow the perceptual system of the decision modules to determine meaning; it must be able to describe the current state of the environment so that a decision can be made; it must be a medium by which the actions of a government can be transmitted between and within governments. In fairness to those who have taken the events coding approach, it should be mentioned that these demands upon the language are much more severe than those of the events people. They wish only to describe very gross types of behavior, while we have to express not only the type of behavior, but also the substance of the act. While severe demands are made of the language, because of the



conceptual power of the approach to language building through a grammar, the task in some ways is simplified. Because of the nature of the approach the entire problem can be broken down into separable (not separate) clusters. Rather than being forced to consider the language as a whole, it can be broken down into the problems of a grammar, sentential forms, and objects.

As an example of the power of the approach, consider the rough specification of a language in Figure IV. The structure specified in

-----FIGURE IV ABOUT HERE-----

Figure IV is not the specification of a grammar. It only gives 20 basic sentential forms. It is the structure of a language -- not a specification. The structure could become a specification with the inclusion of a set of actors and actions. But even on a structural level, the language reveals a considerable degree of power. Sentence forms 3, 4, 5, 6, 12, and 13 are sufficient to generate a language of greater complexity than the 63 WEIS coding categories (McClelland and Young, 1969). For example sentence 12 could be represented as a threat, promise, the offer of a proposal, a demand, a warning, or an ultimatum (to use some of the WEIS categories). In addition, the six forms alone can generate sentences of greater complexity and sophistication than WEIS or any other coding scheme can specify. For example: Since X will not do A then if X does B, Y will do C. This sentence structure represents the embeddings of sentence type 1 in type 6. It is this ability of a grammar to define embeddings in a recursive manner that accounts for its generality and power. As a further indication of both the power of the approach and the demands being placed upon the language, suppose that the OI for Saudi Arabia receives these three sentences:



- 1) The total wheat crop is X bushels.
- 2) Y men are employed in farming.
- 3) "Since Israel cannot continue to resist Egyptian aggression if it is not given replacement materials, we [the U.S.] will begin the immediate resupply of Israel."

The perceptual system of the Saudi production system should be able to produce these eight sentences as outputs:

- 1) Labor productivity is low.
- 2) The U.S. will resupply Israel.
- 3) The U.S. is ignoring our threat of an oil embargo.
- 4) The U.S. is still pro-Israeli and anti-Arab.
- 5) The U.S. is supportive of Israeli behavior.
- 6) The total wheat crop is X bushels.
- 7) Y men are employed in farming.
- 8) Labor productivity is Z bushels per man.

This example makes extremely strong demands not only upon the language but also on the production system. But because of the basic power of both production systems and languages the demands are not overly severe.

One of the side pay-offs of this effort at specifying a language for the communication of the decisions of national decision systems is the potential linkage with current events data collection efforts. While the basic approach is somewhat different, there is a very important linkage between the two types of efforts. The decision systems will generate a data source expressible in an event type coding typology. The system should be able to generate the raw data of events data collection efforts. This fact has two important implications: 1) this approach is not alien to much of the work now being done in the field of international relations; and 2) existing events data collections can serve as an important source of validating data. It should be possible to take the output from the simulations (sentences in the language) and code them according to an events coding typology. That coding could be compared to current data sets to assess the amount of agreement. This

interface between events data and our efforts at the specification of language also has the implication that goal seeking propositions could be translated into event type propositions. In addition, the result of these efforts should serve as the basis for a strong theoretical grounding for an even coding scheme. There is a potential source of mutual benefit.

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# Summary, Overview, and Concluding Comments

This paper has covered a wide variety of topics -- ranging from a game called 20 Questions to a consideration of grammars. Through out the course of the development, assertions have been made which must be supported, and promises have been made which must be kept. Some of the assertions concern the nature of the scientific enterprise:

- (1) The binary approach to the construction of theories will not work.
- (2) The binary approach will not work because there is not a specification of the control structure.
- (3) One promising approach to the modeling of control structures is the construction of complete processing models.
- (4) There exists a definite and workable strategy for the construction of complete processing models, based upon the use of generative explanations and simulations.

Others concern the specific approach illustrated in the later portions of the paper:

- (5) A government can be faithfully modeled as a goal seeking system.
- (6) A production system can be specified that will produce behavior characteristic of the behavior of governments.
- (7) A language suitable for the expression of the behavior governments can be specified.
- (8) A production system, that corresponds to point 6, can be specified as a language processor.

These last four are the promises.

Currently, work is under way toward the fulfilment of those four promises. While the implications that I draw from the binary approach are not necessarily shared by my colleagues, the last four promises are the central core of our work. While there is much to

be done, the fact that separable issue clusters have been identified should promote the attainment of the final goal -- a science of nations adequate in power and commensurate with their complexity.

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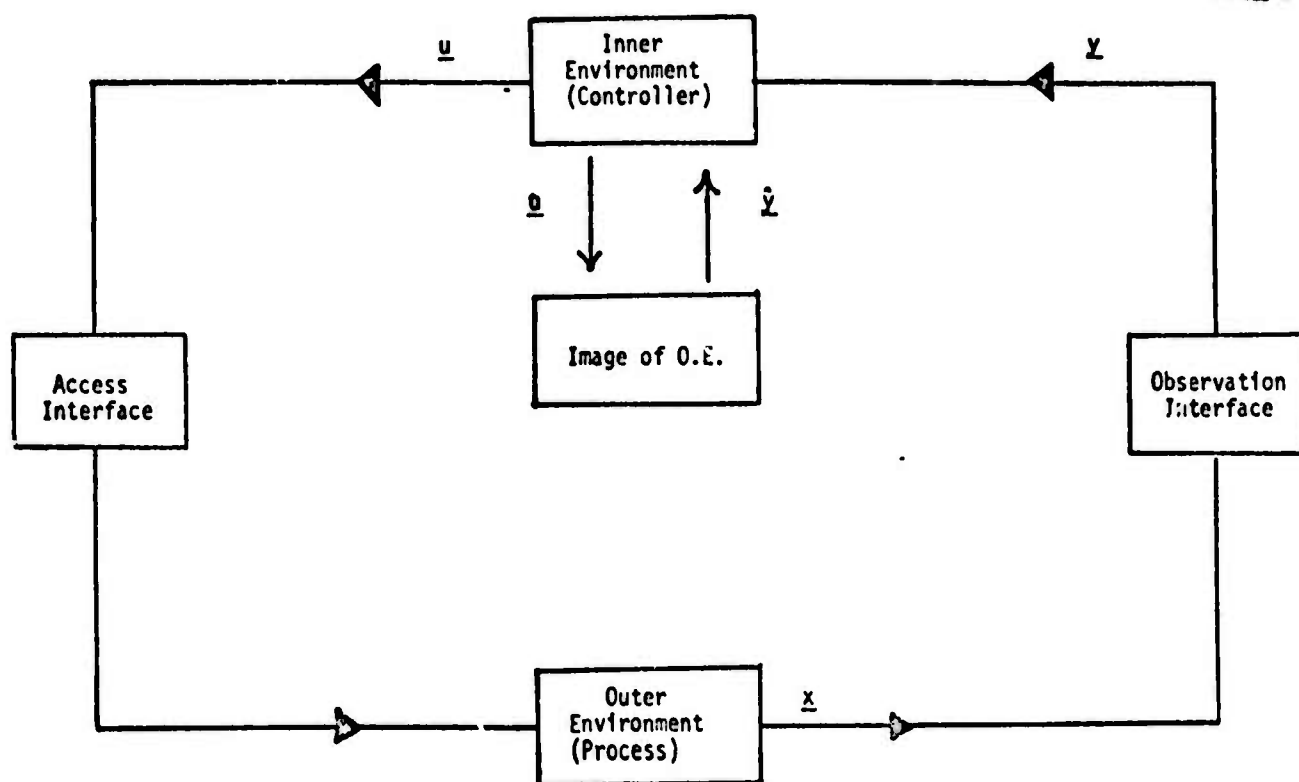


Figure 1 Artificial System Structure

PS: LRCC74

STI: (NIL NIL NIL NIL NIL NIL NIL)

- 1: (STOP) → END
- 2: (REQUEST) → (OUTPUT "RESIGNATION", STOP)
- 3: (MARK, MARK, MARK, MARK) → (OLD(\*\*), REQUEST)
- 4: (FOOD SHORTAGE, FISCAL IRRESPONSIBILITY, NEGATIVE FOREIGN COMMENT BY AN ALLY) → (OLD(\*\*), REQUEST)
- 5: (FOOD SHORTAGE) → (OLD(\*\*), MARK)
- 6: (SUPPORT OF RADICAL FOREIGN CAUSES, NO ACHIEVEMENT) → (OLD(\*\*), MARK)
- 7: (SUPPORT OF RADICAL FOREIGN CAUSES, SFRC, SFRC, SFRC) → (OLD(\*\*), FISCAL IRRESPONSIBILITY)
- 8: (FISCAL IRRESPONSIBILITY) → (OLD(\*\*), MARK)
- 9: (NEGATIVE FOREIGN COMMENT BY AN ALLY) → (OLD(\*\*), MARK)
- 10: (BAN CIGARETTES or BAN ALCOHOL or BAN LUXURIES) → (OLD(\*\*), ORTHODOXY)
- 11: (ORTHODOXY, ORTHODOXY, ORTHODOXY, ORTHODOXY) → (OLD(\*\*), MARK)
- 12: (FOOD SURPLUS, MARK) → (OLD(\*\*))
- 13: (SUPPORT RADICAL FOREIGN CAUSES, ACHIEVEMENT, MARK) → (OLD(\*\*))
- 14: (INCREASE IN SKILLED LABOR, MARK) → (OLD(\*\*))
- 15: (SADAT HAS TROUBLES, MARK) → (OLD(\*\*))
- 16: → READ

\* SFRC = SUPPORT OF RADICAL FOREIGN CAUSES

Figure 2 A Simplified Production System

## FIGURE III

PS: SAAC74

STI: [NIL NIL NIL NIL NIL NIL NIL NIL]

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13: <(LAND PRODUCTIVITY LOW) → OLD(\*\*) (INCREASE LABOR) (INCREASE MECHANIZATION)>

14: <(LAND PRODUCTIVITY FALLING) → OLD(\*\*) (INCREASE LABOR) (INCREASE MECHANIZATION)>

15: <(LABOR PRODUCTIVITY LOW) → OLD(\*\*) (INCREASE LAND) (INCREASE FERTILIZER) (INCREASE IRRIGATION)>

16: <(LABOR PRODUCTIVITY FALLING) → OLD(\*\*) (INCREASE LAND) (INCREASE FERTILIZER) (INCREASE IRRIGATION)>

17: <(LAND PRODUCTIVITY HIGH) → OLD(\*\*) (INCREASE LAND) (INCREASE FERTILIZER) (INCREASE IRRIGATION)>

18: <(LAND PRODUCTIVITY RISING) → OLD(\*\*) (INCREASE LAND) (INCREASE FERTILIZER) (INCREASE IRRIGATION)>

19: <(LABOR PRODUCTIVITY HIGH) → OLD(\*\*) (INCREASE LABOR) (INCREASE MECHANIZATION)>

20: <(LABOR PRODUCTIVITY RISING) → OLD(\*\*) (INCREASE LABOR) (INCREASE MECHANIZATION)>

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AN AGRICULTURE CONTROL

PRODUCTION SYSTEM

FIGURE IV

- 1: <ACTOR> <CAN|CANNOT> <ACTION> <ACTOR>\*
- 2: <ACTOR> <COULD|COULD NOT> <ACTION> <ACTOR>\*
- 3: <ACTOR> <WILL|WILL NOT> <ACTION> <ACTOR>\*
- 4: <ACTOR> <SHOULD|SHOULD NOT> <ACTION> <ACTOR>\*
- 5: <ACTOR> <DID|DID NOT> <ACTION> <ACTOR>\*
- 6: <ACTOR> <IS|IS NOT> <ACTION> <ACTOR>\*
- 7: WILL <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>\*
- 8: SHOULD <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>\*
- 9: DID <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>\*
- 10: IS <ACTOR> <DOING|NOT DOING> <ACTION> <ACTOR>\*
- 11: CAN <ACTOR> <DO|NOT DO> <ACTION> <ACTOR>\*
- 12: IF <....> THEN <....>
- 13: SINCE <....> THEN <....>
- 14: <....> BECAUSE <....>
- 15: <....> SO THAT <....>
- 16: <....> AND <....>
- 17: <....> OR <....>
- 18: <....> IF <....>
- 19: <....> AND NOT <....>
- 20: <....> OR NOT <....>

\* Optional; the actor (target) may be omitted.

| means that one of the two choices should be selected.

... means that any one of the 20 sentential forms may be selected.

SOME COMMENTS ON THE STATE OF  
GENERAL SYSTEMS THEORY \*

Warren R. Phillips  
CACI, INC.  
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## SOME COMMENTS ON THE STATE OF GENERAL SYSTEMS THEORY

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## ABSTRACT

This paper presents a review of three major problems in the current development of General Systems Theory as represented by J.G. Miller's Living Systems. The three topics deal with: (1) the analytic representation of the adaptive nature of complex systems, (2) the hierarchical nature of information and authority in complex systems, and (3) the dynamic nature of the decision problem. Each topic is developed in terms of recent additions to theory in the systems approach.

James G. Miller has suggested that a "general systems theory" can be developed by abstracting properties peculiar to physical, biological, and social systems.<sup>1</sup> The primary emphasis of this approach is on ascertaining the substantive properties shared by the various systems.<sup>2</sup> This attempt, however, has not been altogether successful. In part, success depends upon the state of the art in each discipline corresponding to the level of analysis upon which the theory focuses. Serious difficulties have arisen at the more macro-systems level, particularly in political science and international relations. General Systems Theory embraces the notion of teleology at most system levels; but the versions of General Systems Theory practiced in political science and international relations tend to strip away the heart of the formulation leaving, in most cases, an empty input-output shell with which to work. This is due, at least in part, to the rejection of the structural-functional approaches to political development. It may also be the result of a lack of understanding of the need for decision algorithms or goal-seeking apparatus in General Systems Theory. This shortcoming stems primarily from a lack of formal development of the systems theoretical approach. The concepts developed in that approach are too often furthered by the use of analogy and metaphor. This paper is an attempt to examine some of the major concepts which, in recent years, have been developed beyond the level of sophistication present in the current versions of Living Systems and the whole General Systems Theory perspective. It will deal with systems at the national level and reference both national and supernational systems.

## THE ADAPTIVE NATURE OF COMPLEX SYSTEMS

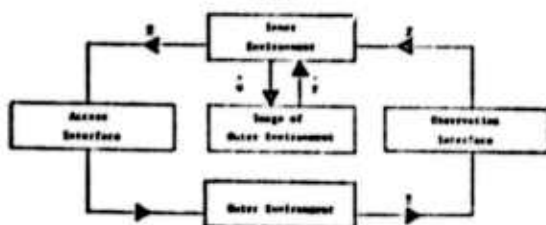
Systems of the nature we are examining are artificial or adaptive in a very specific way.

They are as they are only because of a system's being molded, by goals or purposes, to the environment in which it lives. If natural phenomena have an air of "necessity" about them in their subservience to natural law, artificial phenomena have an air of "contingency" in their malleability by environment (Simon, 1969: ix).

An adaptive system is one that produces (generates) outputs in such a manner as to attain or seek to attain certain goals. Adaptive systems respond to environmental changes by altering policies so as to minimize the discrepancy between policy outcomes and predetermined goal states.<sup>3</sup> In the area of energy policy, for example, a goal might be to maintain present demographic distribution patterns in a particular region, perhaps Western Europe. Faced with environmental changes that reduce the availability of crude oil, then, an adaptive system might seek to convert electrical production from a procedure based on oil to one based on coal while retaining high levels of gasoline production. If this policy allows continuation of suburban and rural living and lengthy commuting, the system has successfully adapted to this environmental change.

Adaptive systems have a number of components. There is an inner environment (I.E.) which attempts to achieve goals in an outer environment or task environment (O.E.). The inner environment receives information (reduced quantity of crude oil) about the outer environment through an observation interface. Similarly, the inner environment implements its decisions (alters electrical production functions) through an access interface. In order to evaluate alternative policies without actually implementing them, the inner environment must have a representation or image of the outer environment. The structure common to adaptive systems is shown in Figure 1.

Figure 1



This structure is very similar to the problems studied by control engineers. From a control perspective, the inner environment would be labeled the controller and the outer environment, the process to be controlled.<sup>4</sup>

The easiest way to explain this perspective is to examine the energy policies that were discussed above. Let the inner environment be an energy office in an international organization such as the EEC, which is responsible for allocating crude oil for various refined products and setting price levels for those refined products. Let us further stipulate that the officials' goals are to maintain present community patterns and present demographic distributions of population in country members.

Information concerning the state of the environment is now represented by the vector  $X$  and might include the use of public transportation, new cars sold, and movement to and from suburban areas. The officials must have some way of observing  $X$  so that they can determine whether their goals are being acceptably met. However, they cannot observe every sales transaction or every family move directly. In fact, even if they could obtain all of this information, it would probably exceed their information-processing capability. Therefore, they need a mechanism that filters the minute information into manageable form. This is the task of the observation interface.

The observation interface is the inner environment's sensing device for gauging changes in the outer environment. In this example it might include the various agencies that collect and aggregate data on gasoline availability and price, automobile usage, automobile purchasing, etc. To avoid information overload from  $X$ , the observation interface might incorporate an indicator system. Thus, instead of having a lot of information about the outer environment ( $X$ ) as an input, the inner environment receives  $Y$ . Vector  $Y$  might include such indicators as changes in the level of public transportation use and changes in the rate of new car purchasing. In some cases  $Y$  and  $X$  will be equivalent. Most often, however,  $Y$  will be some summary measure of  $X$  and the notation reflects this distinction.

An important research question stemming from this perspective concerns just what information is needed to accomplish policy-makers' goals and how such information should be filtered and utilized in the policy-making process. We assume

that many of the quantitative indicators or event analyses in international relations today could be used to address this particular question if goals and purposes were built into that particular research approach.<sup>5</sup>

Upon receiving  $Y$ , the inner environment must evaluate it to determine what sort of policy is indicated. Results of this evaluation will depend on the nature of  $Y$  and on the inner environment's image of the outer environment. The image might, for example, consist of an economic model in which the critical variable is the price elasticity of gasoline for private transportation use. Generally, this image will, at least in part, contain the elements of  $Y$ . In this way  $Y$  can be used to set the state of the image, and various policy alternatives  $U$  can be put into the image to assess the differential impacts  $Y$ . To have any impact, the elements of the  $U$  vector must have some way of entering the outer environment; that is, the inner environment must have some access interface that can implement  $U$  in the outer environment. Refinery allocation, gasoline rationing, and price adjustments might serve as access points for the officials in this example.

Of course, the model structure outlined here merely identifies the important characteristics of adaptive systems. For theorists to implement goal-directed policy effectively in a changing environment model, the system must be capable of:

- Specifying systems' goals in terms of desired characteristics in the environment in which policy is implemented,
- Possessing an access interface with the outer environment which permits it to alter that outer environment,
- Maintaining a realistic mental image of that outer environment which allows it to gauge the impact of alternative policy actions prior to their actual implementation and,
- Possessing an observation interface with the outer environment which permits it to monitor changes in the outer environment constantly and efficiently and to assess the actual effect of the already implemented policies with respect to goals.

Assuming that the system has an identifiable set of goals and possible alternative policies, a model of the process requires an "image" of the outer environment and an observation interface for monitoring that outer environment. The goals provide criteria for utilizing policy alternatives to regulate change in the outer environment. There are three aspects of this decision process that characterize nations as systems: (1) nations are goal-seeking systems, (2) nations hold many goals simultaneously, and (3) nations are responsive to a perceived rather than an objective environment. The last of these

assertions is seen in the development of images in the above adaptive systems approach. The first, that nations are goal-seeking, stems directly from the whole adaptive systems approach and is consistent with the position held by Snyder, Bruck, and Sapin (1962), the Sprouts (1956), and Holsti, et al. (1968, 1965) on foreign policy decision-making and international relations. That nations hold many goals simultaneously is the crucial element that distinguishes them from most lower level systems. This is one of the most difficult aspects in the development of a general systems theory for large, complex systems. When dealing with nations or supranational units, social scientists must deal with the fact that there is no single goal that can adequately describe the operation of the system. If the goals of the system are inconsistent, one goal can be achieved only at the expense of the other. In that case the system (nation, organization, or individual) must determine which trade-offs are acceptable. Even if the goals are consistent, all goals may not be achieved at the same time because the systems have only a finite amount of resources. Again, the system must determine the optimum allocation of resources.

#### HIERARCHICAL SYSTEMS STRUCTURE

In recent years the foreign policy decision-making literature has suggested that the relationship between foreign policy decision-making responsibilities and information-collecting and distribution responsibilities is an integral aspect of effective organization performance. Edward Morse states the case succinctly: "Channeling and handling information has become an organizational problem no foreign ministry has mastered" (1970: 356). The process suggests that there are patterns of behavior that are strongly influenced by organizational position. Hillman (1971), for instance, describes organizations in terms of the network of interpersonal relations at various levels. There seems to be a recognized agreement between policy-makers and academics on the existence of levels of authority, on the interaction of motivation and goals, and on the impact of information on preferred modes of action at different levels of the policy process. Some of the elements of these concerns can be made explicit if we introduce modern systems theories that treat organizations as multilevel systems. The concept of a multilevel hierarchy structure cannot be defined by short, succinct statements. What can be done at this point is to (1) introduce some basic concepts for classification and study of our systems in general, (2) provide a conceptual foundation for the problem of coordination, and (3) indicate some features of hierarchical systems that make them attractive for use in the study of large-scale decision systems.<sup>6</sup>

The total national system can be designated as a simple scheme in Figure 2, plus the ongoing process of foreign policy inputs and outputs. (See Figure 3 for a much more abstract version.)

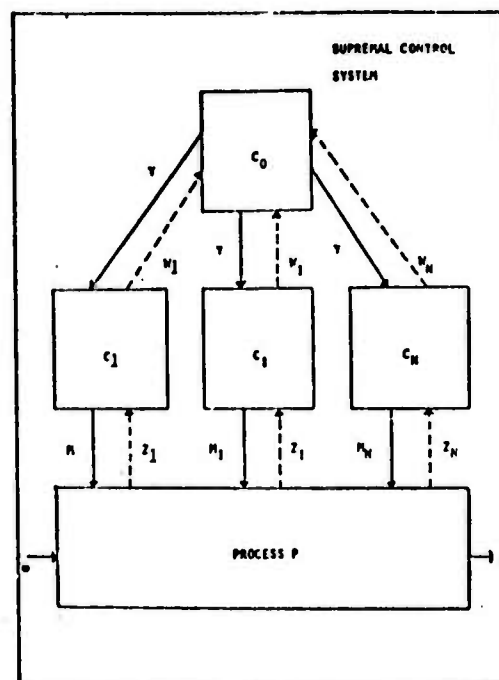


FIGURE 2 - A TWO-LEVEL SYSTEM WITH N INFIMAL CONTROL SYSTEMS AND A SINGLE SUPRAMAL CONTROL SYSTEM\*

\* TAKEN FROM PESAROVIC, ET AL., 1971, P. 26

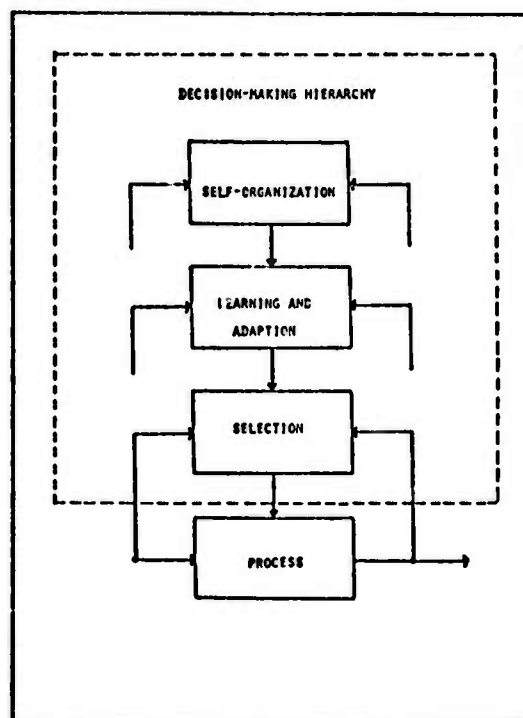


FIGURE 3 - FUNCTIONAL MULTILAYER DECISION HIERARCHY\*

\* TAKEN FROM PESAROVIC, ET AL., 1971, P. 86



The operation of a subsystem on any level is influenced directly and explicitly by the higher levels, especially the immediately superseding level. This influence, while not always binding, reflects the priorities set by the higher levels. The influence is termed intervention. Priorities are oriented downward in a command fashion; but the success of the overall foreign policy system and indeed of the units on any level depends upon the performance of all units in the system. Since a choice of action tacitly assumes that intervention precedes the actions of lower units, the success of the higher units depends upon that action or the resulting performance of the lower level units. Performance can be viewed, therefore, as a feedback and response to intervention. Feedback is oriented upward as shown by the performance feedback channels (the upward arrows in Figure 2). Each of the layers that we have laid out can be divided into functional decision hierarchies.

The functional hierarchy should contain three layers as shown in Figure 3. The lowest level, the selection level, accepts the information from outside the units and applies a decision algorithm to derive a course of action. The algorithm must be defined as an organizational means of reaching a solution to a specific intervention from above.

The goal of the second-layer activity, the learning and adaptation level, is to reduce uncertainty. Given a set of priorities and goals and the importance of actions from a higher level, this learning or adaptation layer must decide how to respond to the needs prescribed from above. This layer must reduce the uncertainty in making responses and initiatives as much as possible, providing a simplified job for the selection level.

The self-organizing layer must select the structure, functions, and strategies that should be used on the lower layers so that an overall goal or set of national interests can be pursued as closely as possible. It can change the directions for action of the first level if the overall goal is not accomplished, or change the learning strategy used on the second layer if the estimation of uncertainties proves to be unsatisfactory.

We can formalize the coordination of activities at this point. Consider the process  $P$  with two inputs: a control of intervention input from the second level ( $m$  from a given set  $M$ ) and an input  $w$  from a given set  $\Omega$ , called the input. It also has an output  $y$  in a given set  $Y$ . The process  $P$  is assumed to be a mapping.

$$P: M \times \Omega \rightarrow Y$$

In foreign policy terms, the process or selection level concerns the execution of daily actions in each of the bureaucracies involved in foreign policy. The tasks here are to apply an algorithm for responding to stimuli from the environment which has been provided by the

second level. While it is true that some policy is made in the "cables," these changes in the algorithms for responding must be in harmony with the objectives passed down from above or there may be requests for a change in activity.

The second level in our control system has two inputs: coordination  $\gamma$  provided by the higher level from a given set  $\Gamma$ , and the feedback  $z$  from a given set  $Z$  coming from the process. The output is the control intervention  $m$  selected from the set  $M$ . The system is a mapping:

$$C_1: \Gamma \times Z \rightarrow M_1$$

At a managerial level, the task of coordinating the organizing goals of the administration with the realities of the daily routine must be carried out. It is here that decisions about the feasibility of particular plans are decided. These levels must provide policy plans for operators to use as algorithms in acting. This level must suggest plans, get them accepted by the administration, and implement them at the selection level.

The highest level is responsible for coordination. It has only one set of inputs, the feedback information  $w$  from the second level which it uses to arrive at the coordination output. The system is assumed to be a mapping.

$$C: W \rightarrow \Gamma$$

where  $W$  is the set of feedback information inputs  $w$ . Except in rare instances, such as a crisis, the administration level sets national interests, chooses a policy plan, or combines suggestions of several plans from the managerial level and assigns responsibility to a lead bureau at the second level; but it does not involve itself in the process directly.

To complete the description of this system we must specify the nature of the feedback information. The feedback information  $z$  to the second level contains direct information on the process  $P$ ; it is therefore a function of the control  $m$ , the disturbance  $w$ , and the output  $y$ , given by the mapping:

$$f_1: M \times \Omega \times Y \rightarrow Z_1$$

Similarly, the feedback information received by the highest level contains information concerning the behavior of the second level and is therefore assumed to be given by a mapping:

$$f_0: \Gamma \times Z \times M \rightarrow W,$$

which is a function of the coordination  $y$ , feedback  $z$  and output  $m$ .

It should be pointed out that this functional hierarchy is based on the conceptual recognition of the essential functions in a complex decision system. It provides only a starting point for a rational approach to assign proper functions to different layers. In fact, each functional



layer can be implemented by further decomposition. For our purposes it is only essential to lay out the elements of the decision-making process and to borrow this functional hierarchy of levels or tasks so that we can demonstrate at what place a specific form of forecasting might be beneficially used. In order to do this, we need to make a set of assertions about the types of planning appropriate to each of these levels.

In spite of several common features, the tasks and roles of the system can be differentiated by levels at this point:

1. A higher level unit is concerned with the broader aspects of the overall foreign policy behavior. This is reflected in the fact that a higher level unit is superior to two or more units and its decisions determine the activities of the lower levels.
2. The decision period of a higher unit is longer than that of lower units. Lower level units are responsible for today's decisions, that is, whether to respond to previous actions or to initiate new actions. Hence, the time frame of these decisions is quite limited. However, to evaluate the effect of coordination, higher levels cannot act more often than the lower levels, whose behavior is conditioned by this coordination. Therefore, it is essential to recognize inherent differences in the time frames of most decisions as we proceed up the decision hierarchy. Certainly there are specific strategies or issues, such as the Cuban Missile Crisis, when the normal process is shortcircuited by making most decisions operative at a much higher level in the hierarchy.
3. A higher level unit is concerned with the slower aspects of the overall system's behavior whereas the lower levels are concerned with more particular local changes in the foreign policy process. The higher levels cannot respond to variations either in the environment or in the process itself which are faster than the variations of concern to the lower levels.
4. Descriptions and problems of the higher levels are less structured with more uncertainties and are more difficult to formalize quantitatively. Decision problems in the higher levels can be considered more complex and an approximation can be used to derive a solution to a higher level problem; but accuracy is then reduced. One has to be cautious when interpreting the results.

In general, for any level there is a specific set of techniques suitable for solving respective forecasting problems. According to the system characteristics, units of the higher echelons are concerned with broader aspects of

the foreign policy task and therefore have a more complex decision problem than those at the lower levels. They have a longer time frame with which to look at problems, and therefore are concerned with slower aspects of the overall foreign policy behavior. As we turn to specific forecasting techniques and review their capabilities we should keep in mind these characteristics so that we can decide at which stage and at which level in foreign policy decision-making and planning the techniques are applicable.

The point that needs reemphasizing at this stage is that at each of the nodes in Figure 2, decisions must be made that result in outputs. These decisions are based upon information concerning the current state of the process and by goals either passed down in the form of interventions or decided upon at this level. But uncertainty exists at each stage and in the process of reaching decisions, forecasts of the likely impact of these decisions must be made. At certain levels responsibility for dealing with uncertainty is limited to issues with low levels of complexity. This is especially the case at the process level. In issues of higher complexity, managers or senior political officers may be brought into the decision. It is not only the case that different individuals or levels in the hierarchy are involved at different levels of uncertainty, but that different routines for handling uncertainty and information in forecasting must be employed. This brings us to the decision problem.

Three decision problems are associated with this system:

- $D$  is the overall decision problem reflecting an exogenously given objective function, for example, a social welfare function in an economy.
- $D$  is the set of  $N$  infimal decision problems reflecting the goals of each infimal participant.
- $D^0$  is the decision problem of the coordinators,  $C^0$ .

If we assume that  $D$  is given and known, and that certain critical characteristics of the system are known and unchangeable, such as the distribution of power and information, then we can define the active coordination problem as follows:

Definition: The active coordination problem is to find a coordination scheme,  $CS$ , implying a coordinator's decision problem,  $D^0$ , such that there exists a coordination input  $g^* \in G$  with the properties that:

- a.  $g^*$  solves  $D^0$ , and
- b. solution of  $Dg^*$  implies the solution of  $D$ . (Here  $Dg^*$  represents the infimal decision problem  $D$  parameterized by  $g^*$ ).

Recognizing that the subprocess interactions of  $C^0$  give rise to the need for active coordination in a system, Mesarovic, *et al.* developed three modes in which interaction might be handled. These modes are called interaction decoupling, interaction prediction, and interaction estimation. Each mode is suited to classes of systems with specific distributions of power and information, a point which is relatively poorly made by the authors. Brock (1971) discusses the problem in some detail and extends the Mesarovic work by reviewing the way Aoki (1970) and Baumol and Fabian (1964) handle the issues of power and information distribution in hierarchical systems. The issues are little more than recognized at this stage in the development of formal theories in a systems perspective. But obviously if we are to adapt large, complex systems to perhaps even more complex environments we need to deal with the organizational approaches to this problem.

#### DYNAMIC DECISION RULES FOR COMPLEX SYSTEMS

Of the many approaches to the study of political phenomena, none has achieved more mathematical development than decision-making. It has been most frequently applied to conflict behavior (Axelrod, 1970) and strategic deterrence (Ellsberg, 1964; Hunter, 1971) in foreign policy. More specifically, previous developments have focused on decision rules which, if followed, will allegedly yield a "best" course of action (at least under the conditions specified). Unfortunately, previous rules tended either to make unrealistic simplifying assumptions or were so mathematically complex as to be less than adequate for explaining decision-making in the "real world."

The primary guide to the decision rule's formulation may be found in Chernoff who suggests the following:

In a given problem, the statistician should first eliminate those strategies which are obviously bad. He should then dispose of some of the remaining which, while not so obviously bad, still fail to make the grade. After a certain amount of elimination, the remaining strategies will be considered adequate. The statistician will have no reason to prefer any of these strategies to the others. The set of these adequate strategies will be called the solution to the problem. It is not implied that the statistician necessarily considers that two elements of the solution are equivalent (1954: 427).

In this solution set, then (which is termed the region or class of acceptable decisions), it is not assumed that a complete and strong ordering exists among the alternatives, although that may in fact prove to be so.

The major drawback to most decision approaches is that the algorithms are static and not dynamic (Phillips and Yarnell, 1974). This

assumes that the outer environment and the system's goals remain constant. Edwards notes, with respect to static approaches, that:

In any case the decision maker chooses and executes one of his courses of action, receives the value or payoff associated with the intersection of that course of action and the state of the world which actually obtained--and then the world ends. The decision maker (in principle) never gets to make a second decision in which he might apply whatever he may have learned as a consequence of the first.

In dynamic decision theory, decision makers are conceived of as making sequences of decisions. Earlier decisions, in general, produce both payoffs and information; the information may or may not be relevant to the improvement of later decisions. The objective of the decision maker may be taken to be maximization of total profit over the long-run. But it is quite likely to be desirable to give up short-run profit in order to increase long-run profit. The most common instance of such a conflict would arise in situations where some courses of action lead to more information and less profit, while others lead to less information and more profit (1962: 59-60).

Much has been written to date about decision-making in institutions (e.g., government bureaucracies), and from this research has come the notion of "bounded rationality." Hughes cites three implications of "bounded rationality":

First, problems are generally broken up into quasi-independent parts, and the decision-makers deal with these parts individually....

Second, rather than maximizing or optimizing, decision-makers will satisfice. That is, rather than considering all alternatives, and choosing one calculated to produce the most desirable consequences, organizations will select an action calculated to be "good enough." Organizations have some notion of what constitutes minimally acceptable performance, and resources devoted to decision-making beyond that level will seldom be committed. Another way of looking at this...is that there is a point beyond which the costs of greater than the expected benefits of improved action....

Third, decision-makers are working in an environment of uncertainty concerning the consequences of their actions, and will act in such a way as to minimize that uncertainty. One major implication of this has been developed by Lindblom (1959). In order to obtain feedback concerning the consequences of policy, decision-makers will act incrementally and frequently, rather than attempting to completely solve a problem with initial action (1972: 19-20).

Bounded rationality, with its emphasis on feedback of performance and with its reliance on satisficing, mitigates against a static approach and moves toward a dynamic one.

A dynamic approach would probably be very difficult. Edwards suggests why:

In dynamic situations, a new complication not found in the static situations arises. The environment in which the decision is set may be changing, either as a function of the sequence of decisions, or independently of them, or both. It is this possibility of an environment which changes while you collect information about it which makes the work of dynamic decision theory so difficult..." (1962: 60).

He goes on to suggest six different relations between the type of environment (stationary vs. non-stationary), and information about the effect of decisions on that environment. Each relation might specify a different decision rule. Edwards (1962) also presents a model of a probabilistic information processor which fits (analytically) either into the artificial system of Thorson (1973), or the hierarchic modeling of Hughes (1974), Bossel and Hughes (1973), and Mesarovic and Pestel (1972).

Let us state the problem as follows: Supposedly we are attempting to keep a system on some given path. This path may be the result of some prior optimization or it may represent some *ad hoc* goals such as full employment, price stability, or a target rate of growth. Further, let us assume that this path is feasible for the system. Finally, suppose that we have a choice of the following classes of policies: (1) policies based on the predictors of the role of state variables at some time in the future; (2) policies based on observations of the state variables at the present time; (3) policies that do not depend in the short run, on either estimates or observations of the state variables. Having first defined a suitable metric on the notion of stability, our problem is then to select the policy that will result in the stability for our system when (1) there are errors in the measurement of the state variables; (2) there are lags in the observation of the state variables and/or the action of the controllers, and (3) the control can be varied only in discrete amounts.

The tools with which this might be accomplished are also being developed. Obviously, the mathematics of controlling dynamic systems would be essential; here, too, Mesarovic, *et al.*, (1970) come to mind. But it is uncertain as to how such analytic and mathematic techniques may be incorporated into a decision rule; that is, while dynamic programming and satisficing rule out linear programming and hence game theoretic spinoffs, they don't specify a unique rule as an alternative. We might propose satisficing, which as a rule says to adopt the first minimally acceptable alternative. Suppose "minimally acceptable" refers in particular to  $k$

dimensions or variables; i.e., the alternative must be minimally acceptable on all  $k$ . An alternative now comes up for evaluation. By what rule is it to be accepted or eliminated? It may be argued that satisficing says the following: If one is  $.X$  certain that this alternative will generate at least  $Y_i$  ( $i = 1, 2, \dots, k$ ) utility, then it is accepted; otherwise it is rejected. There are then  $k+1$  parameters to be specified by the decision-maker.

The major advantage to this rather simple but novel representation of satisficing is that it sensitizes the decision-maker to the parameter  $X$ , a probability. This, together with the view of probability as a function of information (i.e., entropy), sensitizes the decision-maker to issues such as (1) whether to delay implementing any decision until more information is acquired in order to raise  $X$ , or at least to get a better "fix" on it; (2) when the decision-maker should stop acquiring information (Brock, 1969); and (3) the importance of having a good descriptive theory since such a theory provides information as to the more effective alternative. Finally, the explicit representation of  $X$  ought to permit more valid simulations, since obviously the range of the search over alternatives is a function of  $k+1$  parameters: (1) the degree to which the state of the outer environment is not consistent with essential values--the  $k$  parameters--and (2) the degree of certainty with which the decision-maker views the effectiveness of the alternative--the  $k+1$ st parameter,  $X$ . Most simulations simply deal with the first  $k$  parameters and ignore  $X$ . Current work in economic development demonstrates that myopic rules can be developed which do indeed reflect the information problem present to decision-makers without reaching a level of unrecognizable mathematical manipulation (Nelson and Winter, 1973; Kelly, Williamson and Cheetham, 1974).

#### FOOTNOTES

1. See Miller (1973, 1972, 1971a, 1971b, 1971c, 1965). See also the Yearbook of the Society for General Systems Research. Prominent among the exponents of General Systems Theory are L. Von Bertalanffy, K. Boulding, R.W. Gerard as well as Miller.

2. Perhaps the most skeptical review of this work can be seen in Simon and Newell (1965). Simon (1969) presents a more recent review of the prospects of such a synthesis.

3. Several theorists have considered an adaptive model in the examination of social systems as particularly viable for the study of changing conditions. Among the most important are Ashby (1952); Campbell (1965); Pringle (1968); and Buckley (1967).

4. This development was first suggested by Stuart Thorson (1973). Since then both Thorson and I have applied it to the energy production problem of Middle Eastern countries, to the need to develop appropriate standard operating pro-

cedures for crisis monitoring and management (CACI, Inc., 1974c; Phillips and Thorson, 1972), and to problems of the intelligence community (CACI, Inc., 1974b).

5. See Phillips (Forthcoming 1975) for a review of events literature. For the use of quantitative indicators see CACI, Inc. (1974a). Also look at Hermann (1971); McGowan (1970); and McClelland and Hoggard (1969).

6. The development of this application of control theory stems from the work of Mesarovic, et al. (1970). For other suggestions of similar approaches see Steinbruner (1973) and Burgess (1972).

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Toward a Theory of Dimensions for  
the Social Sciences\*

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### Abstract

Although the concept of dimension is widely used in social science research, its conceptual foundations remain unspecified. This is apparent in the lack of specificity with regard to diversity in conceptual meaning, necessary assumptions, inherent limitations and relatedness between concepts. The analysis offers a preliminary solution to this problem by identifying four concepts of dimension. Each concept may be distinguished on the basis of a rigorous logical, empirical and theoretical foundation. The foundations require that certain assumptions be met in order to utilize each concept. Given the assumptions necessary for determining each concept, certain limitations may be identified. By establishing the foundations in this analysis, it is possible to heirarchically arrange the four concepts so that each may be used in conjunction with certain kinds of research undertakings. The ultimate purpose of the analysis is to (1) establish a preliminary conceptual framework so that each concept may be fully elaborated in subsequent analyses and (2) posit a framework with which to evaluate the use of each concept in various empirical and theoretical enterprises.

## Introduction

One concept which is used extensively in the social sciences is the concept of dimension. Some scholars use the concept to refer to categorization schemes for classifying the components of a phenomenon. Lazarsfeld, for example, speaks of "latent structures" which may be used to classify "manifest data."<sup>1</sup> And Clausen develops a theory of "policy dimensions" which may be used to understand legislative decision-making<sup>2</sup>. Other scholars use the concept to express some mathematical structure which may reflect relationships between important components of a phenomenon. Torgerson, for instance, uses the term to refer to an "attribute" of a particular property of a stimulus-object.<sup>3</sup> Anderson, et. al., in their methodology for legislative roll call analysis suggest that dimensions are equivalent to the number of "factors" which express a given number of correlated variables in terms of a lesser number of uncorrelated ones.<sup>4</sup> Still other scholars use the concept to refer to the similarity among measurable aspects of a phenomenon. Rumelhart and Greeno, for example, hypothesize that the "similarity" between stimuli influences individual choice behavior.<sup>5</sup> Tversky and Russo use a similar concept in their study of "interstimulus similarity" and "substitutability" in binary choices among alternatives for individuals.<sup>6</sup>

The applications of the use of the concept of dimension illustrate its ubiquitousness in the analysis of social science phenomena, especially with regard to their variegated substantive references. The applications suggest that the generic concept of dimension masks some highly differential semantic uses of the term in ordinary language. And the applications indicate that the meaning and use of the concept may vary according to its association with logical and mathematical considerations. The very nature of the applications suggests that the concept is important in understanding social science research.



In spite of the importance of the concept of dimension, the applications are studies much more than the concept itself. This is evident in that it is possible to find many applications, but it is impossible to find a standardized conceptual analysis which will specify the alternative concepts of dimension; the assumptions, implications and shortcomings, explicit and implicit in each concept; and the relationship, if any, which exists between concepts. The concept of dimension is non-standard in its usage across social science research enterprises.

If the concept of dimension is important, yet at the same time non-standard in its usage, then there exists a need for greater conceptual clarity. With this in mind, the purpose of this paper is to (1) sort out the various concepts of dimension into categories which can be used effectively in research; (2) specify the important implicit and explicit assumptions inherent in each conceptual application; (3) offer some possible implications and shortcomings involved in the use of each concept, and (4) arrange these concepts in a useful relationship to one another so that various kinds of research problems may be undertaken.

### I. The Category Concept of Dimension

The first concept of dimension which is apparent in social science research is discovered by employing a conceptual scheme whereby the components of a phenomenon are grouped, matched, pigeon-holed, isolated, analyzed, combined, consolidated or partitioned into any number of equivalence classes or categories.<sup>7</sup> An example of this would be the statement that a congressman's roll call vote can be understood by examining the various components: party affiliation, constituency interest, state party delegation membership, committee assignment and party leadership.<sup>8</sup>

#### Category concept of dimension defined.

Dimensions, according to the above scheme may be defined as any set of mutually exclusive categories or equivalence classes imposed upon a phenomenon

such that each element in the set represents a dimension of the phenomenon. This notion of dimension may be referred to as the "category concept of dimension."

#### Procedure for determining dimensions

It is important to note that no criteria of admissibility has been required or established with regard to categorizing or partitioning. Therefore, to the components of the congressman's roll call vote analysis, one could legitimately add the category of "unicorns." Perhaps this additional category shocks our sensibilities in that it is seen as not only imaginary, but also nonsensical and absurd. To entertain this view, however, is to believe strongly in the notion that somehow there exists a certain order, meaningfulness, relatedness or rationale inherent in the categories themselves. But the categorical concept of dimension only presupposes a purposiveness in an analyst's desire to classify the components of a phenomenon; it does not impose any necessary assumptions as to the relatedness of the categories themselves other than their mutual exclusiveness. In this concept of dimension, "unicorns" are admissible.

Given the above characteristics, category dimensions may serve two functions in social science research. First, they can be used to organize the components of a phenomenon into understandable units for analysis. And second, they can serve as an initial, preparatory step in using a more restrictive concept of dimension.

## II. The Geometrical Concept of Dimension

### Purpose of second concept of dimension

The category concept of dimension above serves to categorize the components of a phenomenon. It avoids the use of assumptions requiring relatedness, meaning, or association between categories. In the second concept of dimension which this analysis will consider, the procedure for defining dimensions will include not only a categorical scheme, but also an attempt to specify some order, relatedness,

association, concatenation, juxtaposition, dependence, similitude (or the converse of these terms) between the categories.

Initially, then, the conceptual scheme to be developed is an attempt to eliminate as many extraneous or "non-dimensional" categories in the categorical scheme as possible by establishing a rigorous criterion which will exclude them from the analysis. This criterion will serve to eliminate categories in two ways: (1) by showing that the categories do not fulfill certain conceptual requirements and (2) by relating the categories together, thereby limiting their number or composition. By way of example, the next procedure will attempt to develop a scheme whereby "unicorns" may be eliminated from the dimensional analysis of a roll call vote, assuming that "unicorns" as a dimension would be undesirable or "non-dimensional." Of course, other categories may be eliminated in the process as well.

#### Foundation for a Second Concept of Dimension

In order to develop a conceptual foundation for the second concept of dimension, it is necessary to require that the concept include the principle defining characteristic of category dimensions, that is, that a phenomenon under analysis must be able to be organized into mutually exclusive categories or partitioned into equivalence classes.

Once the categorization scheme is required, a process for relating the categories or classes must be developed. Although it is possible to relate categories by any number of processes, the second concept of dimension requires that one and only one process be considered for relating categories. The process chosen for the second concept of dimension requires that a phenomenon under analysis be represented as an "arbitrary vector space."<sup>9</sup>

By representing a phenomenon as an arbitrary vector space, it becomes possible to express the categories or equivalence classes of a phenomenon in terms of scalars and vectors. The representation of categories as vectors

suggests two possibilities. The first may be labeled as a linearly dependent vector, or dependent vector. It may be defined as: given  $V$ , an arbitrary vector space, and  $K$ , a field of scalars, a set of vectors  $v_1, \dots, v_n \in V$  are linearly dependent over  $K$ , if there exists scalars  $a_1, \dots, a_n \in K$  not all of them 0, such that:  $a_1 v_1 + a_2 v_2 + \dots + a_n v_n = 0$ . The second may be labeled as a linearly independent vector, or independent vector. It differs from the dependent vector in that:  $a_1 v_1 + a_2 v_2 + \dots + a_n v_n = 0$ , if and only if  $a_1 = 0, a_2 = 0, \dots, a_n = 0$ .

#### Geometrical Concept of Dimension Defined

With the above concepts in mind, the second concept of dimension may be defined as: if the vectors  $v_1, v_2, \dots, v_n$  are linearly independent such that every vector in  $V$  can be represented by these  $n$  vectors, then these vectors form a basis for  $V$ , the arbitrary vector space, and the "dimension" of  $V$  is  $n$ . This may be symbolized as  $\dim V = n$ . Another concept which is identical to this is the concept of dimensionality. When a social science phenomenon is given as above, the "geometrical concept of dimension" is being used.

#### Some Procedures for Relating Dimensions

By using the geometrical concept of dimension, it is possible to reduce the number of categories which might serve as dimensions. First, the categories are greatly reduced in number when an analyst requires that they be utilized only when representable as vectors in a vector space. Once the set of vectors is chosen for analysis, the dependent vectors may be eliminated as possible dimensions since they may be expressed as a combination of independent vectors which are in fact dimensions. In using geometrical dimensions, an analyst is not forced to accept any basis, but is free to manipulate or transform vectors in an analysis to construct any number of different bases. This suggests that vectors derived in an analysis may be treated as dependent in one model and

independent in another.

In order to relate dimensions together, an analyst may perform many different operations upon the vectors in a given vector space. Among these would be scalar multiplication, vector addition and inner product.<sup>10</sup>

Geometrical Dimensions: Some Assumptions and Implications

Having represented a phenomenon under analysis with an arbitrary vector space and having defined dimensions as independent vectors in the arbitrary vector space, an important question occurs with regard to the justification or rationale for such a conceptual scheme. There appears to be at least three reasons which are identifiable. First, the phenomenon may be represented as a vector space model merely by assuming that such a representation makes sense for the sake of analysis. Second, several previous analyses of the phenomenon or similar phenomena may suggest the representation. Or third, an entirely different method of analysis of the phenomenon may suggest the representation. Although these reasons are entirely different in a procedural sense, all three have in common the notion that the phenomenon must be "stipulated" as equivalent to a representation as an arbitrary vector space.

Once the rationale for the use of the geometrical concept of dimension is established, the vector space model of the phenomenon suggests several important implications. First, since dimensions in an arbitrary vector space are equivalent to independent vectors defining the basis of the vector space, it makes no sense to speak of partial or incomplete dimensions in a vector space. Dimensions either exist in this sense or they do not. This is given as an all or nothing proposition.

Second, if during the course of an analysis any portion of the vector space criterion is violated, then the use of the geometrical concept of dimension is curtailed. Violation of the criterion may occur in many forms. One way would be a case wherein an analyst becomes unwilling to accept a theorem



derived from the axioms comprising the vector space model. When this situation occurs, an analyst must either abandon the model or reconstruct the model; but the analyst may not ignore valid theorems and still use the geometrical concept of dimension. And another way which is similar to that above would involve the use of mathematical operations such as vector addition and scalar multiplication. Should a situation arise wherein certain mathematical operations become unacceptable, then the vector space model in use must be abandoned or reconstructed, but the results of valid operations must always be accepted once a model is formulated.

And third, the geometrical concept of dimension may be given as a proper subset of the category concept of dimension. Therefore, what is true for the category concept of dimension is also true for the geometrical; but, what is true for the geometrical may not be true of category dimensions.

#### Formal and Empirical Relational Structures Distinguished

The geometrical concept of dimension as presented requires that any phenomenon under analysis be representable as an arbitrary vector space. An important consequence of this is that empirically diverse phenomena may have the same underlying mathematical structure: the same vector space model may represent a roll call vote, general equilibrium in an economy, and the motion of particles suspended in a liquid. An example of an underlying logical relation in a mathematical structure common to all three phenomena might be the relation "greater than," symbolized ">". The logical relation "<" can be analyzed and manipulated independently of whether one is working with votes, equilibria or particles. When it is possible to speak meaningfully about the underlying mathematical structure without reference to the empirical nature of the phenomenon, then the discussion concerns a "formal relational structure."<sup>11</sup> In addition to manifesting a formal relational structure, an arbitrary vector space may be used to represent an "empirical relational structure," which may be illustrated

by the following: Suppose an analyst observes two phenomena. One concerns a relationship between attitudes, while the other concerns a relationship between physical measurements of length. Now, it is clear that both phenomena may be stipulated to have common logical relations in the same formal relational structure. For example, it may be the case that some component  $x$  is "greater than" some component  $y$  in each phenomenon represented. When the phenomena are examined with regard to their empirical relational structure, however, the simple formal relation becomes greatly modified by the inclusion of empirical components in the relations. Taking the same phenomena, an attitude  $x$  becomes more "intense" than another attitude  $y$ , and a length  $x$  becomes "longer" than another length  $y$ . Clearly, there is an important difference between "intensity" and "length," even though the formal relation "greater than" is the same for both phenomena.

#### Geometrical Dimensions: An Important Limitation

In order to adequately account for empirical relations such as "intensity" and "length" above, it is necessary to develop an explicit, well-formulated theory of measurement. A theory of measurement as a minimum requires a specification of (1) a deductive system consisting of a complete set of axioms and transformation rules to be used in an analysis, (2) a model-theoretic or semantic interpretation of the deductive system in terms of empirical relations, (3) a means for partitioning actual operational definitions and measurement operations into equivalence classes, and (4) a procedure for relating the results of points 1-3 above in a logically consistent manner across a wide range of empirical and theoretical applications.

Requiring a theory of measurement to account for empirical relations as above would greatly reduce the possibilities for analysis in the social sciences, since the level of knowledge in many practical applications is not sufficiently developed to fulfill the requirements of a well-formulated theory of measure-



ment. At the same time, it is desirable in the pursuit of knowledge in the social sciences to attempt to attain as much rigor as possible in dealing with empirical relations, even though certain limitations may exist. This being the case, the geometrical concept of dimension may be seen as dealing primarily with the problem of representing formal relations in arbitrary vector spaces; while the representation of empirical relations is only required to the extent that it is practicable in the particular application under analysis.

### The Usefulness of the Concept

Given the above conceptual scheme, geometrical dimensions serve three functions in social science research. First, they allow for a specification of dimensions in rigorous mathematical terms, that is, independent vectors in an arbitrary vector space. Second, they allow for these dimensions to be meaningfully related to one another through such operations as vector addition, dot product and so on. And third, they serve as preparatory step in developing a third concept of dimension which will adequately account for a well-formulated theory of measurement.

## III. Dimensions as Concepts of Measurement

### Purpose of the Third Concept of Dimension

In the third concept of dimension, an attempt is made to discover a conceptual scheme which will not only account for formal relations as does the geometrical concept of dimension; but also will account for empirical relations. The process for specifying such a conceptual scheme involves finding a means for (1) determining relevant and irrelevant dimensions, (2) determining the completeness of the set of dimensions relevant to a phenomenon, (3) defining a functional relationship between dimensions, (4) specifying the nature and importance of dimensional constants and (5) dealing with

the concept of similarity which becomes important when moving from the phenomenon as a prototype to the phenomenon as a model. In so doing, "intensity" and "length" become important in determining, distinguishing and relating concepts of dimension.

### Foundation for a Third Concept of Dimension

The foundation for a third concept of dimension, based upon an empirical relational structure involves three equally important theoretical concerns. First, the concept of dimension must be compatible with a theory of measurement<sup>12</sup> that allows for (1) the specification and in principle performance of actual operational or measurement procedures upon a phenomenon, and (2) the assignment of an interpretation of meaning to a purely deductive system or formal language. Such a theory of measurement is based upon the interpretation of the concepts: quantity, scale, unit, magnitude, and fundamental and derived measurement.

Second, the concept of dimension must be based upon a specific deductive system or formal language.<sup>13</sup> One such system or language would be first order logic or first order predicate calculus. The deductive system or formal language is important to the concept of dimension in that it constitutes an axiom set which represents (1) the primitive statements or proper axioms used to determine dimensions and (2) the set of rules or calculus axioms used to manipulate dimensions. An axiom set of this kind may be referred to as a "theory" in mathematical logic.

And third, the concept of dimension must be an integral part of a "model" for the deductive system or formal language "interpreted" in light of the meaning (semantics) given in the theory of measurement. A mathematical model for a theory which is realized by the given formal language and theory of measurement may be referred to as a "quantity structure."<sup>14</sup> A quantity structure may be thought of as one kind of empirical relational structure.

# Measurement Theory

One objective of any science is to measure phenomena. Since not all phenomena are measureable, science is limited to measurement of a certain class of phenomena. This class of phenomena will be designated as a set of "quantities." More formally, a quantity is an entity capable of being assigned a numerical value either as a variable or a constant. Two examples of quantity would be time and distance.

In order to determine or designate a quantity, two conditions are necessary. First, there must exist a "rule" for defining the measurement of a quantity. Call this rule a "scale" and let it satisfy the following criteria:<sup>15</sup> (1) makes numerical assignments across every aspect of a quantity and not just a portion of it, (2) the same numerals are always assigned under the same conditions, and (3) there exists the possibility of assigning different numbers to different quantities, or to the same quantities under different conditions. And second, there must exist a "unit" name which specifies precisely the particular scale on which the numerical assignment is made to a given quantity.<sup>16</sup> Examples of units would be seconds and meters.

Units of measurement, for purposes of this analysis, are of two kinds: "fundamental" and "derived".<sup>17</sup> The fundamental units of measurement are those which do not depend upon the measurement of anything else. In physics, for example, the fundamental units are based upon the quantities time, length and mass. The derived units are those which do depend upon the measurement of something else. For the most part derived units may be determined or developed by combining two or more fundamental units. For example, the derived unit "cubic inches" results from the cubing of a quantity length in inches.

One important characteristic of fundamental and derived units is that their initial designation is quite arbitrary. In one system of measurement a unit may be fundamental, while in another it may be derived. A practical

example in physics is that the quantity "force" may be fundamental in one system, given as  $f$ , but derived in another, where force is equal to mass times acceleration ( $f = ma$ ). Once the fundamental units are determined, however, the derived units may be expressed only as combinations of fundamentals. The only real restriction upon the use of fundamental and derived units is that they be used in a logically consistent manner.

Having determined or designated a quantity in terms of scale and unit, the quantity may be measured in fact or treated as being measurable in principle. The quantity being measured, when associated or compared with a unit of measurement may be said to possess "magnitude."<sup>18</sup> More specifically, magnitude is defined as a ratio of a quantity to a unit of measurement. For example, the length of a table is two feet. A magnitude then, may be thought of as an expression or representation of a quantity.

The expression of a quantity as a magnitude must be qualified in one important way,<sup>19</sup> perhaps best illustrated by an example. Suppose a quantity representing a congressman's attitude on welfare policy is measured as a series of responses on an interview questionnaire. Next, suppose that the attitude is measured as a function of some physiological reaction in the congressman's cognitive process. Clearly, both define an "attitude" on welfare policy, yet neither may be converted into the other. In other words, the expression of the quantity as a response cannot be mathematically transformed into the expression of the quantity as a physiological reaction. When this situation occurs, the scales of measurement relating to a magnitude must be referred to as "dissimilar." If the expressions of the quantity could be converted one to another, then the scales must be referred to as "similar." An example of a set of similar scales would be inches, feet, yards and meters.

Even though a quantity is measured by means of a scale and unit, expressed as a magnitude and determined by fundamental or derived units; nothing can

be said about the "actual" or "real" nature of quantities. It is not known whether they are metaphysical, theoretical, logical, empirical or quasi-empirical entities, or, simply nonsensical or meaningless. Therefore, in this theory of measurement, statements about quantities are not to be treated as statements about quantities themselves, but instead are to be treated as statements about scales, units and magnitudes which are expressions or representations of quantities.

### The Quantity Structure

In Part II, the analysis suggested that an arbitrary vector space constituted a model for a theory from which the geometrical concept of dimension could be constructed. Dimensions in this conceptual scheme were defined as independent vectors in a vector space. Empirical relations were discussed under the geometrical concept of dimension, but a well-formulated theory of measurement which would account for them was not imposed upon the model.

It is possible to account for empirical relations and measurement theory in an arbitrary vector space model by restricting the "interpretation" and "realization" of theory so that quantities and their accompanying conceptual framework are included in the semantics of the model. This means that dimensions of a vector space no longer refer to independent vectors in the space, but instead refer to quantities. Of course, quantities are still expressed in the same way as vectors. When the vector space model includes the restrictions imposed by the notion of quantity, the analysis will refer to the model as a "quantity structure."<sup>20</sup>

### Dimension as a Concept of Measurement Defined

It was suggested that units name particular scales of measurement. And it was also suggested that although the units of measurement may be different when comparing several scales with one another, some of these scales may in

fact be viewed as "dissimilar." By combining these notions with the concept of dimension as relating to quantities in a quantity structure, dimension may be defined as a particular class of similar scales used in the measurement of a quantity and expressible as independent vectors in a quantity structure.<sup>21</sup> When this concept is being used, dimensions are considered as "concepts of measurement."

In order to symbolically distinguish quantity structures and dimensions from vector spaces and their dimensions, quantity structures are given as bracketed capital letters, [A], and dimensions are given as bracketed lower case letters, [a].

#### Four Important Properties of Quantities in a Quantity Structure

When the theory of measurement is combined with a quantity structure to form a model, the following properties are appropriate to the analysis of a quantities: (1) quantities are to be measured on a ratio scale, regardless of whether this is stated explicitly or implicitly in an analysis; (2) quantities may be combined multiplicatively; (3) quantities may be combined by division; and (4) it is possible to extract integral roots of positive quantities (for example,  $25m^2$  equals  $5m \times 5m$ ).<sup>22</sup>

#### Quantity Structures and Dimensional Analysis

Having defined quantity structures and dimensions, and having given an account of measurement theory, the analysis will next consider some important restrictions and properties relating to quantity and dimension.<sup>23</sup>

#### Dimensional Equations and Numerical Laws

Once the concept of dimension is defined and the rules for manipulation of the concept are specified, the notion of "dimensional equation" may be developed. A dimensional equation is an equation which defines a relationship between two or more quantities expressed as magnitudes. Dimensional equations

are of two kinds, "definitional" and "empirical."<sup>24</sup> A definitional equation expresses relationships between dimensions of quantities which are true by definition. An empirical equation expresses a proposed relationship between dimensions which are true as a result of an empirical investigation.

Definitional dimensional equations in and of themselves may be "vacuously true" in that they are mathematically true, but are not brought to bare in any empirical way. Empirical equations in and of themselves may be erroneous, since they are potentially at least formally invalid. Clearly, the combination of the definitional and empirical, defined over the quantity structure, provides the most powerful explanatory procedure; since it limits the occurrence of these extraneous statements in an analysis. Of course, it must be noted that what is extraneous in one analysis may not be so in another.

The combination of definitional and empirical equations still allows for many extraneous statements. One way to further limit their occurrence is to require that dimensional equations express only "functional relationships" between dimensions. These functional relationships which limit dimensional equations may be defined as "numerical laws."<sup>25</sup> The most general form of a numerical law may be symbolized as  $y = f(x_1, x_2, \dots, x_n)$ , where  $y$  is a derived measurement expressed as a function of a combination of derived and/or fundamental measurement given as  $x_1, x_2, \dots, x_n$ .

By requiring that dimensional equations be limited to numerical laws, an empirical relation might be represented by the following. First, a quantity may be expressed in terms of magnitudes which represent the results of actual or in principle measurement operations. This is apparent in the necessary use of fundamental measurement operations expressed as classes of similar scales. And second, a quantity may be represented as a functional relationship between magnitudes which also depend upon measurement operations. This is apparent in that many functional relationships are discovered by



empirical testing and simply by formal/deductive manipulation. Both points illustrate the possibility of including extensive empirical considerations in what would otherwise be purely formal relation with empirical labels.

### Dimensional Homogeneity

Dimensional analysis requires and defines an important property of all numerical laws: the "principle of dimensional homogeneity."<sup>26</sup> Briefly, the principle involves the notion that when every magnitude occurring in a numerical law is reduced to its fundamental units of measurement, every term in the equation consists of the same magnitudes raised to the same power. Stated in a slightly different way, the exponent of a dimension of a quantity in any term of a numerical law must be the same as that in any other.

The principle of dimensional homogeneity provides the basis for the notion that the form of the numerical law does not in any way depend upon the choice of fundamental units of measurement in a quantity structure. An example<sup>27</sup> of this may be given as follows: suppose an initial measurement in a consistent system of measurement yields the numerical law  $y = f(x_1, x_2, \dots, x_n)$ . Next, suppose that the units of measurement are changed, yielding the numerical law,  $\bar{y} = f(\bar{x}_1, \bar{x}_2, \dots, \bar{x}_n)$ . If the numerical laws are homogeneous, then the same functional relationships are maintained in the equations even though the units of  $x_i$  are changed to  $\bar{x}_i$ . This suggests that the quantities have a definite relationship with one another independent of the units which may define the measurements upon them. This definite relationship is sometimes referred to as the "absolute significance"<sup>28</sup> of relationships between quantities. At any rate, the relationship is equivalent to a mathematical function which maps the structure  $[A]$  onto itself (i.e.,  $f:[A] \rightarrow [A]$ ) so that the function is one-to-one and onto.

When the numerical laws are dimensionally homogeneous, dimensional analysis can deal with the problem of relevancy of dimensions with regard

to accounting for empirical relations.

To begin with, dimensional analysis can separate the relevant and irrelevant dimensions.<sup>29</sup> Once this is accomplished, the relevant dimensions are retained, while the irrelevant are dropped from the analysis. If the remaining relevant dimensions are complete, that is, if all of the necessary dimensions are given or determined, then dimensional analysis is finished. At the same time, the problem of relevancy is solved. Returning to the example of a congressman's vote, the procedure would eliminate "unicorns" or any other irrelevant dimensions. Note the geometrical concept of dimension eliminated "unicorns" from the basis exclusively by stipulation.

If the set of relevant dimensions is incomplete, dimensional analysis cannot determine what they are. In addition, the analysis cannot indicate what they might be. Therefore, additional empirical or theoretical analysis would be required. Even though this may be the case, it is possible to obtain a partial solution from an incomplete set of relevant dimensions.

#### Dimensional Constants

Just as the principle of dimensional homogeneity restricts the mapping procedure undertaken in a dimensional equation, dimensional constants may also serve to restrict or at least modify these equations.<sup>30</sup> A "dimensional constant" may be defined as a constant of proportionality between two or more quantities expressed as magnitudes. Several well-known dimensional constants in physics are: universal gravitational constant, velocity of light and electron charge.

The importance of the dimensional constant in accounting for empirical relations cannot be over-stressed. Perhaps a simple example from physics will illustrate this point. Suppose an analyst wishes to discover the gravitational attraction between two objects. All of the important quantities and dimensions are given as:

<u>Quantity</u>	<u>Dimension</u>
mass of first body	$m_1$
mass of second body	$m_2$
distance between bodies	$r^2$
time of revolution	$t$

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The most general form of the dimensional equation would be  $t = f(m_1, m_2, r)$ . On the left side of the equation one finds a unit of time, but on the right no such unit is given. Clearly, some expression is missing from the equation which will make the functional relationship true. In this case, the missing element is the universal gravitational constant  $G$ , given as  $m^{-1}l^3t^{-2}$ . The appropriate dimensional equation becomes  $t = Gm_1m_2/r^2$ .

The inclusion of the constant in the equation is important in the following ways. First, the dimensional constant significantly alters the original equation. Second, the constant exists independently of the quantities being analyzed in the analysis. Third, the constant cannot be derived from any combination or manipulation of the given quantities. Fourth, it cannot be discovered a priori, but depends upon the results of related empirical analyses. And fifth, the constant is necessary in order to arrive at an appropriate solution for the equation, or more generally to express a numerical law.

Dimensional analysis, based upon dimensions as concepts of measurement can account for the modifications resulting from the requirement of dimensional constants in some dimensional equations. The possibility of including dimensional constants which are in part empirical adds further reason for believing that empirical relations may be accounted for under this concept of dimension.

### Principle of Similitude

Above, the principle of dimensional homogeneity was shown to restrict functions in quantity structures so that a mapping  $f: A \rightarrow A$  remained the same

regardless of the units used. Sometimes it may be necessary or desirable to perform a different kind of mapping which would take some structure [A] onto another structure [B] using various kinds of transformation operations. For example, it might be useful to build a model<sup>31</sup> airplane, test it in a laboratory, and then by applying various transformation operations attempt to build a full-scale airplane prototype.

As before, the structure of the model and the prototype upon which transformational operations are to be performed are of two types. The first is the formal relational structure which involves the logical properties of the representation of a phenomenon. The operations which are appropriate to this structure are those appropriate to any arbitrary vector space. And further, all results of appropriate operations must be accepted in order to use the arbitrary vector space model. The second is the empirical relational structure which involves some logical properties and some empirical ones. All appropriate operations and the results of these operations which apply to the formal structure may not be acceptable when performed on the empirical relational structure. When they are appropriate to the empirical structure, the "principle of similitude"<sup>32</sup> is being utilized. The principle may be stated as follows: there exists the possibility that the primary and secondary quantities of a quantity structure are such that an equivalent quantity structure may be constructed which are exactly similar to the initial expression of the quantity structure.

The airplane example above provides a means whereby the difference between transformation operations in the formal relational structure and those in the empirical relational structure may be illustrated. Suppose that an aerodynamic engineer constructs a model airplane and tests it in his laboratory. The model performs as predicted. Next, the engineer constructs a full-scale prototype of the model. A test pilot flies the prototype airplane and it

crashes. A subsequent analysis of the environmental factors shows that this was not the cause of the crash. The prototype as a scaled transformation of the model remains as the only possible source of trouble. One explanation for the crash is that the model and prototype differ according to some "scale factor influence."<sup>33</sup> This refers to the fact that even though transformations on a formal structure may be valid, there may be additional modifications which are empirically necessitated, but which are not indicated by any of the formal requirements. In the airplane example, the engineer may modify the prototype by incorporating changes which are necessitated merely as a function of moving from one size model to another.<sup>34</sup>

Dimensions as concepts of measurement can account for the problems relating to the principle of similitude, either by requiring that operations upon empirical relational structures maintain a certain similitude or by showing that similitude is not a problem in performing a particular operation on a particular empirical structure.

#### Relationship Between Geometrical and Measurement Dimensions

The quar structure with its explicit notion of dimension gives use to additional rigor and restriction with regard to the arbitrary vector space model given in the geometrical interpretation of dimension. This is accomplished primarily by means of the inclusion of measurement theory in a model-theoretic quantity structure. This suggests, therefore, that dimensions as concepts of measurement might be viewed as a proper subset of the geometrical concept of dimension.

#### A Potential Problem

The methodological underpinning of dimensions as concepts of measurement consists of a concatenation of the empirical, theoretical and formal in such a way that each is important in developing a theory of dimension. In addition,

each must be weighed against the other so that scientific explanation becomes in many ways a synthesis of these components. The clearest instance of this occurs when transformations from models to prototypes are undertaken. The theoretical and formal aspects of the model and prototype suggest that the results of a transformation may be valid; but a comparison of these results with the empirical results of measurement operations suggests that these transformations must be modified by adding in "scale factor" influence in order to match the theoretical/formal solution with the empirical solution.

These modifications (transformations having only one case) usually are not thought of as anomalies, but instead appear to be the result of measurement error or incomplete information about the nature of this problem under analysis. One question arises from this: are these modifications the result of imprecision and insufficient information, or could they represent an incorrect conceptualization of the concept of dimension? In other words, is there a fourth concept of dimension which could eliminate these anomalies?

Unfortunately, the method cannot answer these questions within its own conceptual framework. To illustrate this it is only necessary to review the method in a cursory way. First, certain theoretical, formal and empirical considerations are formulated in order to construct a quantity structure which is stipulated as representing a phenomenon. Next, some components of the quantity structure are operationally defined, either in fact or in principle. Then, measurements are performed and results are obtained. And, the results are compared with the initial theoretical, formal and empirical considerations. These results either support the initial considerations or are used to modify them. Once this process is completed it begins over again ad infinitum.

These representations are essentially arbitrary and are limited only in terms of logical consistency, validity, applicability and convenience. There-

fore, if an anomaly in one representation is to be understood or eliminated, then it is necessary to construct another representation. One problem with this is that the representations can only be evaluated in terms "relative" to one another. They cannot be evaluated in terms which are "absolute." Clearly, this is a function of the arbitrariness of the method. It is apparent then, that there exists no means whereby one can transcend the method itself in order to evaluate any representation.

The problem of anomaly as presented above seems to offer two alternatives. The first would suggest that the problem is in fact a shortcoming or limitation in the use of dimensions as concepts of measurement; but that the effects of the problem can be ameliorated or understood in most cases so that the problem may not be as severe as it first appears. At any rate, even if the problem was severe, there is no way to solve it. The second would argue that the problem is in fact severe in cases where it is known to exist, but even more important, there exists a possibility that its ultimate effects may go unnoticed thereby undermining the entire approach. The solution to the problem of anomaly for this alternative seems to lie in the examination of the "absolute" nature of the phenomenon and not its "representation" relative to something else.

In one sense, the third concept of dimension may serve as a preparatory step in developing the criteria for a fourth concept of dimension.<sup>35</sup> In another, depending upon the possibility of developing the fourth concept of dimension, it may serve as a final or ultimate concept of dimension.<sup>36</sup>

#### IV. The Absolute Concept of Dimension

##### Purpose of the Fourth Concept of Dimension

Dimensions as concepts of measurement allow for an adequate treatment of empirical relations by constructing models which are quantity structures. One



problem arises when using this concept, however, and this involves the possibility that a phenomenon may be represented by stipulating an infinite number of quantity structures. The problem with this is that certain anomalies may arise when comparing or moving from one structure to another. The problem may be one of measurement imprecision on the one hand, or insufficient knowledge on the other.

In the fourth concept of dimension, analysts may accept measurement imprecision and insufficient knowledge as courses of anomaly, but they suggest that these may also be caused by the "arbitrariness" and "relativity" in presenting quantity structures for analysis. Therefore, the purpose of the fourth concept is to eliminate arbitrariness and relativity, and substitute in instead, a notion of some "absolute" representation of a phenomenon.

#### Foundation for a Fourth Concept of Dimension

In the development of the empirical, formal and theoretical foundations of the categorical, geometrical and measurement concepts of dimension, it was possible to specify precisely the nature, assumptions and limitations of each. Unfortunately, no such precision exists with regard to a specification of the foundation of a fourth concept of dimension. For the most part, mention of the concept has been either limited to mere allusion suggesting that the concept is the next logical step to be taken after the development of dimensions as concepts of measurement;<sup>37</sup> or, mention has been in the form of a categorical rejection of the concept.<sup>38</sup> At any rate, little or nothing has been forthcoming concerning the precise nature of the concept or even its possibility.

#### A General Sketch of the Concept

Since there is no information concerning the foundations for a fourth concept of dimension, on a superficial treatment of some possible characteristics of the concept may be given. Of course, it will be impossible to state how this

foundation may be achieved or even if such a foundation is possible. The following constitutes a catalog of some important considerations.

1. A theory of measurement might be developed which would not be based upon operational definitions and measurement operations, but instead upon some actual, knowable characteristic of the phenomenon itself. If this were not possible, then a weaker version of this measurement theory would require that only one operational definition or set of operational definitions actually characterizes a phenomenon, while the others would be rejected as meaningless or nonsensical in absolute terms.
2. An axiom set would be necessitated such that every axiom accounted for or characterized every component and relation of a phenomenon derived from the theory of measurement.
3. A model which would "realize" both the theory of measurement and formal theory aspects of a phenomenon would require specification. The model would then constitute a homomorphism with the knowable properties of the phenomenon itself.
4. Quantities, scales, units, magnitudes and dimensions would be unique and invariant with respect to a given phenomenon. Similarly transformations between units, scales and magnitudes would then be eliminated.
5. The quantities, scales, units, magnitudes and dimensions of a phenomenon would be combined to form dimensional equations and numerical laws according to one and only one functional relationship which is unique and invariant.
6. Dimensional homogeneity would characterize each valid dimensional equation.
7. Dimensional constants would be eliminated in the sense of not being discovered in another separate empirical analysis. Instead, dimensional constants would be unique and invariant in each dimensional equation characterizing a phenomenon.

8. The principle of similitude would apply, but there would exist no ameliorating or modifying effect due to scale factor influence.

A concept of dimension which manifests at least the eight criteria above may be referred to as the "absolute concept of dimension."

#### Some Strategic Considerations in Searching for Absolute Dimensions

One group of scholars argue that the absolute concept of dimension does not or could not exist. Therefore, it is meaningless, as well as costly to attempt to develop such a framework. Another group argues that absolute dimensions have not been found simply because the proper questions in the proper framework have not been asked, so that an effort in this direction would be of great value. The proponents of the former argument cannot legitimately reject absolute dimensions outright since they cannot transcend the relativity considerations inherent in the fabric of their own method. The adherents of the latter position, having proposed no method for defining and discovering absolute dimensions, cannot show that there are grounds for accepting the existence of absolute dimensions.

The solution to this impasse seems quite simple. To begin with, it is hard to see why the development of absolute dimensions, if they do exist, would not arise out of some crisis in scientific explanation which dimensions as concepts of measurement could not account for. This being the case, both groups should be able to participate in any ongoing scientific paradigm, although their individual purposes in some ultimate sense would be quite different.<sup>39</sup> In this way, no additional costs are accrued and no a priori acceptance or rejection of the concept is entertained. Research would continue in spite of the lack of resolution of this theoretical problem.

## V. Conclusion

The analysis above identified four related concepts of dimension which may be of use in the social sciences. The first of these was discovered by classifying the various components of a phenomenon. Dimensions derived from this procedure are referred to as "category dimensions" so that each classification constitutes a single or separate dimension.

Once category dimensions are determined, a second concept of dimension may be developed. This involved a conceptual scheme such that a phenomenon is treated "as if" it were an abstract vector space with its components given as either dependent or independent vectors. This is based entirely upon the willingness of an analyst to "stipulate" the equivalence of a phenomenon and a vector space. Dimensions found by this procedure are referred to as "geometrical" concepts of dimension, and are equivalent to independent vectors in the arbitrary vector space. The advantage of this method over the categorical is that the procedure allows for the specification of the "relationships" between dimensions in mathematical terms.

Building upon the geometrical concept of dimension, it is possible to determine a third conceptual scheme whereby dimensions are not only categorized and formally related, but also allow for a representation of empirical relations in a model. The procedure which determines this conceptual scheme is based upon a "realization" of a theory of measurement and an arbitrary vector space as a mathematical model given as a "quantity structure." Dimensions found in this method refer to classes of similar scales, which represent independent vectors in a quantity structure. Dimensions are characteristic of quantities and based upon operational definitions or measurements performed.

It is not clear whether measurement dimensions can be restricted further to construct a fourth concept of dimension. But, assuming that one can or

that this should at least be attempted, the fourth concept of dimension would allow for a transeendence of the dimensions which relate exclusively to sets of operations, and attempt instead to apply the concept of dimension directly to an absolute representation of the phenomenon itself. The purpose of the procedure would be to eliminate relativity arising out of a combination of measurement theory and model theory. If this method were possible, dimensions of a phenomenon would be "absolute."

The four concepts of dimension are arranged so that the absolute is a proper subset of the measurement, the measurement of the geometrical and the geometrical a proper subset of the categorial. This may be illustrated in the following Venn diagram.

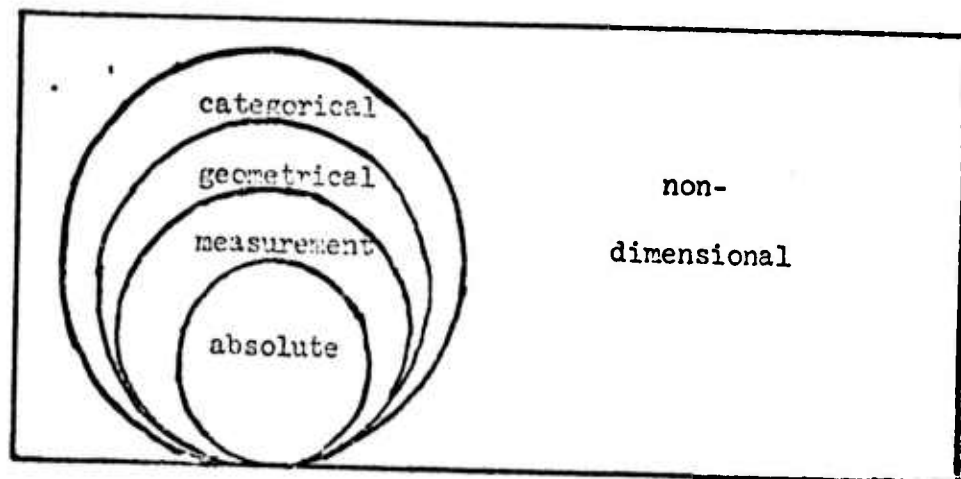


Figure 1

The advantage of arranging the concepts in this manner is that the results of an analysis based on one concept can be used as a preparatory or initial step in an analysis using a subsequent concept of dimension.

The above classification scheme for dimensions is not intended as a "cookbook" procedure for specifying how one would go about discovering dimensions in a social science research enterprise. Instead, it is a conceptual analysis which relates a rigorous framework for determining whether or not a concept of dimension is being used, and if so which one. In order to accomplish this, each concept is catalogued according to its assumptions, relationships, implications and limitations all of which indicate what one should mean when using any concept of dimension.

Once the above conceptual framework is established, it should be possible to accomplish in subsequent analyses three additional undertakings: first, various research enterprises both empirical and analytical may be analyzed in terms of the four concepts of dimension to see how the concept is applied. Second, once the applications are examined, additional analyses might be undertaken to ascertain whether or not an application is assumed to have properties unwarranted by the concept of dimension being used; or whether or not a more rigorous concept of dimension might be warranted in an application. And third, the conceptual analysis of dimension may serve as a preliminary basis for the development of a problem framework which would suggest more elaborate and extensive applications, limitations and shortcomings, explicit and implicit, in each concept of dimension above.



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A Revised Agricultural Sector Simulation Model  
for Saudi Arabia\*

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## The Context\*

Oil clearly has been a dominant factor in the economies of the oil-producing countries of the Middle East. Yet, to focus entirely upon oil is to view a rather distorted picture of these countries. For despite the tremendous wealth derived from oil production, there has been little appreciable change in the overall economic situation in these countries. But then the economic development of each country depends upon much more than the accumulation of capital surpluses, upon more than the growth in productivity of a single economic sector. It also depends heavily upon the modernization and development of other economic sectors, particularly the agricultural sector.

Recognizing the importance of the agricultural sector to the economies of these oil-producing countries we have attempted to construct a simulation of that sector as viewed by the decision-makers in each country.<sup>1</sup> More precisely, we have sought in this paper to formulate a structure which will enable us to (1) identify and trace the various information and material flows in the agricultural production process that influence the decision-makers' choices of developmental policies and programs, and (2) project the consequences that their choices might have for the outputs of the agricultural sector. To this end, we have adopted what we term a "building-block" approach to modeling the agricultural sector.

With this "building-block" approach, the complex array of variables and relationships comprising the agricultural sector is conceptually

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grouped into several sequentially-linked "logical components" (or building blocks) to simulate various facets of the production process. Four such components are included in the present version of our model: resource allocation, modernization, production, and consumption/demand components. The output from each component serves as either an input to another component or a performance measure, or both. The final outputs of the model thus include not only physical outputs, but also a set of performance measures. It is this set of measures which the decision-makers evaluate and compare with policy goals when choosing their policies and programs for the next time period.

At present, then, we have a model which is structured to simulate the production of field crops (specifically wheat, the principal crop and food staple in the five oil-producing countries examined here). Parameter values as well as initial values for the variables have been collected for Saudi Arabia. Utilizing these values we have made several test runs of the model. The results of these preliminary runs suggest that despite some apparent substantive and technical shortcomings in the model, the relationships expressed in the model are logically consistent. Moreover, the outputs generated during these runs seem to make sense substantively.

#### The Setting: Agriculture in the Middle East

Agriculture constitutes a major sector of both the economy and the social structure of each of the five Middle Eastern countries examined in this study. After oil, it is the largest single contributor to the national account (i.e., the national income, the GNP, the balance-of-payments, etc.) of each country. And, whereas

the oil sector represents the major source of revenue for these countries, the agricultural sector is the principal source of employment and individual income. More than half of the population in each country (except Libya) derive their livelihoods directly from agricultural production. In Libya's case this figure is considerably smaller (approximately one-third of the population), but it still represents the largest share of the population involved in any one sector of the Libyan economy.

Despite this rather sizable input of labor into the agricultural sector, agricultural productivity in these countries remains rather low. Winter grains such as wheat and barley, (the principal grain crops in these countries), for example, rarely yield more than fifteen bushels per acre per year, even in relatively good years.<sup>2</sup> At such levels of productivity, these countries are barely able (if at all) to produce enough on their own to meet the present needs of their respective populations. All too often they must import large quantities of food to "fill up" their frequently-deficient food accounts. Confronted with ever-growing populations and rising demands for better standards of living, their countries are thus likely to become even more dependent upon external sources of food. In an age where these countries are fervently trying to establish their economic independence, the prospect of becoming increasingly dependent upon other countries for food would clearly seem to represent an anathema. But unless agricultural productivity can be significantly raised above present levels (or otherwise augmented), these countries are likely to experience widespread famines in the not-too-distant future.



To avert the possibility of famine, considerable efforts are thus being made in these countries to modernize and develop their agricultural sectors. If these efforts are to succeed, however, several rather formidable obstacles must be overcome. One such obstacle which has long constrained agricultural production in these countries is their relative lack of adequate water supplies.

For the most part, these countries depend upon rainfall to provide the water needed for crop production. But because of the arid nature of the climate in these countries, the rainfall is both low and highly variable over time. Many areas of these countries, in fact, received so little rain as to make the production of rainfed crops well-nigh impossible. As a result, the amount of cultivable land in each country is limited to a very small percentage of each's total land area. And where this land is actually put under cultivation, the utilization of this land for rainfed crops (which the major share of the crops grown in most of these countries are) requires the adoption of such practices as placing the cropped area in fallow during alternate growing seasons. Under such conditions it is hardly surprising that these countries have thus far been unable to realize their full agricultural potential.

The alternative to this dependence upon rainfall for crop production is, of course, the extension of irrigation to the areas to be cultivated (both present and potential). But to bring these areas under irrigation requires that these countries have alternative sources of water in sufficient amounts to meet the water requirements of the area (and crop) to be irrigated. Of the five countries, however, only

Iraq appears to be endowed with such a supply of irrigation water. Specifically, with a combined average annual flow of around 61 million acre-feet, the Tigris and Euphrates rivers provide Iraq with great irrigation potential.<sup>3</sup> Utilizing only part of this potential (i.e., approximately 28.4 million acre-feet), the Iraqis can presently put an estimated 7.5 million acres of crop land under irrigation.<sup>4</sup>

The other four countries do not possess any readily-accessible supplies of irrigation water which are comparable to those found in Iraq. Iran, it is true, also relies upon the Euphrates for irrigation water. The amount of water it extracts from this source is considerably less than that extracted by Iraq, however. And as such, this source is, by itself, insufficient to meet Iran's present and projected water needs. The situation is even bleaker for Algeria, Libya and Saudi Arabia; there are no rivers, lakes, etc., of any potential significance in these countries.

From where, then, can these four countries get the water they need for irrigation? One source is to be found underground, i.e., groundwater from underground streams and lakes. Information on how extensive the supply of this water is, however, is rather scanty. A more certain source of potential irrigation water is, of course, seawater. But the production costs involved in tapping this source, as well as those associated with groundwater, are substantial. The cost of producing groundwater, for example, presently runs around \$130 per acre-foot.<sup>5</sup> This contrasts sharply with the cost of desalinated water which, given present technology, costs an estimated one dollar per 1000 gallons, or about \$326 per acre-foot.<sup>6</sup> As these countries have to dig deeper wells, and as desalination technology

advances, however, the difference in the costs of these two alternative sources is likely to diminish.<sup>7</sup> But for the present time (and for the foreseeable future), it is the production of groundwater which, in terms of cost, constitutes the more practical solution to the water problem in these countries.<sup>8</sup>

Whatever the source, it is abundantly clear that the development of irrigation is an essential component of any effort to raise agricultural productivity of these five countries. However, expanded irrigation is not the only prerequisite for increased agricultural production: "Indeed, neither water nor any other single input is the magic wand that will quickly and painlessly produce agricultural plenty and prosperity".<sup>9</sup> Thus, if the expansion of irrigation in the cultivated areas is to be of any value, it must be accompanied by a number of additional but equally important production inputs. After all, the scarcity of water does not constitute the only obstacle to the expansion of agricultural production in the five countries.

Another major obstacle to increased agricultural production is the general lack of soils suitable for cultivation. Suitable soils are as scarce in these countries as water, if not more so. As a consequence, only a small fraction of the land in each country is truly cultivable. Even in those areas where cultivation is feasible, the suitability of the soil is limited. In particular, there are two aspects of the soils in these countries which pose major limitations upon agricultural production. First, with continued wetting and drying out, the soil has a tendency to accumulate a high concentration of salt. This problem is especially great in Iraq where between twenty and thirty percent

of the cultivable land has to be abandoned each year due to salination. Second, the soils are very low in nitrogen content. Nitrogen is necessary to sustain high production in these soils. As a consequence of both limitations, the productivity of the soil tends to be exhausted rather quickly with the result that much of the cultivated land must be placed in fallow during alternate years. Moreover, even when this land is cropped, the resulting yields tend to be quite low.

Clearly, then overcoming this second obstacle constitutes another major prerequisite for increased agricultural production. But again, no single input will be sufficient to achieve this. Instead, there are several separate but closely interrelated inputs which should help improve the suitability of the soils for production. Among these is, first of all, the construction of a drainage system for "flushing" harmful salts out of the soils. In conjunction with this, these countries need to improve their use of land and water. What this specifically entails is the adoption of such practices as land leveling, flood control, and moisture conservation. Additionally, more extensive use must be made of fertilizers, particularly nitrogen fertilizers. Both potassium and phosphorus fertilizers are available in these countries, but not in sufficient amounts to sustain a wide variety of crops at high production levels. From oil, however, these countries could derive the needed amounts of nitrogen fertilizer, although this would require sizable investments in the development of the appropriate production facilities. Finally, with increased fertilization and irrigation, new varieties of crops could be introduced which are of the high-yield type.

All of the inputs identified above, including the extension of irrigation, are directed at raising the per acre yields of the cultivated lands in these countries. But raising per acre yields represents only one aspect of the overall problem of increasing agricultural production. Another equally important aspect of this problem is that of raising the per capita productivity of labor.

As we noted at the beginning of this report, a major share of the population (and thus the labor force) in each of the five countries is engaged in agriculture. Yet, the per capita productivity of agricultural labor is presently quite low. Faced with insufficient water supplies and poor soils, the individual farmer, of course, is not going to be very productive. But even with the necessary inputs to overcome these two obstacles, he is still not likely to be very productive. For to raise the per capita productivity of agricultural labor in these countries, two obstacles must be overcome. The first of these relates to the availability of labor in sufficient numbers to support an intensive effort to expand agricultural production.

Of those employed in the agricultural sector, most are engaged in traditional subsistence farming. With agricultural production thus being directed primarily at meeting the food needs of the individual household (or production unit), the labor input required to produce this food is provided principally by the household itself. And, more often than not, this labor is sufficient to meet the labor requirements for subsistence farming. With the movement away from subsistence farming and toward expanded production, however, ". . . the need for labor will increase so considerably that present surpluses (if any

exist at all) will hardly suffice to satisfy the new requirements."<sup>10</sup> Put somewhat differently, by raising production yields these countries are likely to create another problem for themselves, namely, the problem of shortages of labor. There are no other sources of labor in sufficient amounts which these countries can draw upon to meet prospective labor requirements. The situation is further aggravated by the fact that the agricultural sector loses part of its labor supply each year. This loss of labor results not only from normal attrition (e.g., death, retirement, etc.), but also from the movement of sizable numbers from the rural areas to the cities.

How, then, is the problem of labor shortages to be overcome? One way, of course, is to substitute machinery for human labor, i.e., to "mechanize" the agricultural sector. At present the level of mechanization in these countries is rather low; farmers still depend largely upon human and animal power. Thus, to increase the per capita productivity of the existing labor supply (and, in turn, to decrease the amount of labor required for the intensification of agricultural production), these countries will have to input sizable amounts of farm machinery (e.g., tractors, harvestors, etc.). Farm machinery, in this sense, constitutes both a labor-saving device and a means to increase production.

But is the inputting of this machinery enough? To reiterate a point made earlier, the introduction of any single input (such as farm machinery) is not by itself sufficient to bring about the desired changes in agricultural production. Thus, ". . . mechanization would accomplish relatively little unless accompanied by better

irrigation and drainage, greater fertilizer use, better crop varieties, better control of weeds and crop diseases, and by other components of a technologically advanced agriculture. . . ."<sup>11</sup>

Nor is the mere inputting of these factors of production together enough. There must also be a willingness on the part of individual farmers to adopt these production inputs. What this essentially boils down to is the existence of economic opportunities that are rewarding to these farmers. Herein lies the final obstacle to increased agricultural production to be discussed here, namely, the relative lack of such opportunities in these five countries.

As Schultz (1964) has noted, traditional agriculture (which agriculture in these countries predominantly is) has certain built-in resistors to any change in the existing state of the art: "The concept of traditional agricultures implies long-established routines with respect to all production activities."<sup>12</sup> And because farmers in traditional agriculture have a wealth of experience with these routines to draw upon, the risks and uncertainties associated with the production possibilities of traditional factors of production are minimal. But with the introduction of new factors of production, these farmers are faced not only with having to break with the well-established practices of the past, but also with having to cope with risks and uncertainties which are as yet unknown.<sup>13</sup> As a result, they are likely to be rather hesitant to adopt these new factors. Yet, it is only through experience that they will be able to learn what the risks and uncertainties inherent in these factors are.



But how are those engaged in traditional agriculture to be induced to try these new production inputs? The answer to this question lies in the economic opportunities that agricultural production and, in turn, the use of these new inputs offer to the farmer. More precisely, the willingness of individual farmers to adopt the new production inputs depends largely upon (1) the payoffs to their production activities, and (2) the costs (as well as the supply) of these inputs. What this essentially means is that there must be a system of prices which will enable farmers to make a reasonable margin of profit and, at the same time, to obtain the necessary new inputs at prices that permit this profit margin. It is this margin of profit, then, that provides the necessary inducement, or lack thereof, to adopt the new production inputs.

In the five countries examined here, however, such a system of prices is, for the most part, missing. Prices for farm products in these countries generally tend to be depressed and distorted. Moreover, the costs of the required inputs remains quite high. The overall effect of the present system of prices thus has been to leave farmers in these countries with relatively small margins of profit, if any at all. As a result, there is little incentive for them to produce much more than what is necessary to meet their own consumption demands, let alone to purchase the new production inputs.

Clearly, the establishment of a more efficient system is essential to overcome this final obstacle. But again, the overcoming of this one obstacle is not, by itself, enough to bring about an increase in production. True, an efficient system of prices is likely

to lead to an increased willingness on the part of farmers to grow more, but their efforts will not get very far unless there are adequate supplies of the necessary production inputs available.

In sum, then, the essence of agricultural development in these five Middle Eastern countries lies in

. . . the application of a package of separate but closely interrelated programs, technologies, and processes; it is their interrelationship which is truly significant. . . Any single program may have limited and sometimes even negative effect, if taken by itself; but may be highly productive if combined with other programs in proper proportions and proper timing.

The problem facing decision-makers in these countries thus is one of finding that proper combination of programs, in the proper sequence, which will produce the results they seek.

As the preceding discussion indicates, the effort to modernize the agricultural sector in the five countries examined here is clearly no simple matter. There are numerous physical, economic, social and political factors, the dynamic interactions between which affect the decision-makers' choices of developmental policies and programs. To provide a clearer picture of how this complex array of factors and their interrelationships affect these choices, we have constructed a simulation model of the agricultural sector in these countries. What this model purports to offer is a way (1) to identify and trace the essential information and material flows influencing the decision-makers' choices, and (2) to analyze and project the consequences that their choices might have for the performance of the agricultural sector.

To simplify the picture even further, we have confined our attention in the construction of this model to the production of but one crop:

wheat. This narrowing of focus is based, in part, on the fact that wheat constitutes the principal crop grown in these countries in terms of both the quantity produced and the amount of crop land devoted to it. Moreover, wheat represents the major staple in the diets of the people in these countries. Finally, we contend that even with this focus on one crop we will still be able to present a fairly representative picture of the setting within which decisions on the development of the agricultural sector are made in these countries. That is to say, we hold that the structure of the model (i.e., the equations) will remain similar whether we are dealing with the production of wheat, barley, dates, or vegetables. What will change, of course, are the values for the parameters and variables included in the model. But now let us look at the model itself.

In constructing our model of wheat production, we have employed what we shall term a "building-block" approach.<sup>15</sup> Basic to this approach is the assumption that the system to be modeled is composed of several functionally interrelated "building-blocks." Linking these components are the outputs of the components themselves. That is to say, each component yields an output (or set of outputs) which serves either as an input to another component in the system, or as a measure of the component's performance. Collectively, the performance measures generated by these components comprise a "performance vector" which, in turn, serves as an input to the decision stratum (i.e., as the information upon which the decision-makers' base, for the most part, their choices for the next time period).

### The Model

This section will describe the four components (resource allocation, modernization, production, and consumption/demand) which make up the agricultural sector model. Simplifying assumptions have, of necessity, been made in each component. However, for the sake of clarity each component's description will be brief and (for the most part) the simplifying assumptions will be considered in a separate section at the conclusion of this paper.

Considerable revision of the model has been undertaken. The changes correct errors which were discovered in earlier versions and also make the model more appropriate for use in simulating the wheat sector of Saudi Arabia. Still, the model should be considered an initial effort which will doubtless require revision. Suggestions or comments from readers of this paper are encouraged and will be gratefully received.

#### A. RESOURCE ALLOCATION

The first component (or "building block") deals with the allocation of resources for wheat production. First we shall consider the allocation of land.

In our model, the amount of cultivable land available is assumed to remain constant throughout the simulation run. This assumption is based on the further contention that it will be some time (say thirty years or so) before these countries are likely to make any marked progress towards expanding the amount of cultivable land. Not all of this cultivable land, of course, is actually cultivated at any one time. Both the nature of the soils and the prevailing farm practices necessitate the placing of some of this land in fallow each growing season.

A distinction is made between rainfed land, which is farmed with traditional methods, and irrigated land, which is farmed with modern methods. We assume that for Saudi Arabia the amount of rainfed land available is constant throughout a simulation run. The policy-maker may only influence the amount of this land that is used for wheat production. This is expressed in the following equation:

$$\text{TOTRFAW} = \text{P1} * \text{TOTRFA} \quad (\text{R1})$$

where:  $\text{TOTRFAW}$  = rainfed land to be used for wheat production (hectares)

$\text{TOTRFA}$  = total rainfed land (hectares)

$\text{P1}$  = the proportion of total rainfed land to be used for wheat production (dimensionless)

On rainfed land in most of Saudi Arabia, however, cropland may be used only every other year. Thus we have the equation:

$$\text{RFAWEAT} = 0.5 * \text{TOTRFAW} \quad (\text{R2})$$

where:  $\text{RFAWEAT}$  = the amount of rain-fed land available for wheat production in any given year (hectares)

The allocation of irrigated land is somewhat more complex; a policy-maker must determine how much irrigated land is available each year as well as decide how much of the available land is to be devoted to wheat production. The amount of irrigated land available at any time is a result of past expenditures on irrigation development, and hence the amount of land available at some future time is dependent upon present expenditures. Our model includes the following assumptions about irrigation development projects:

- 1) Any development project will take a known time to complete.
- 2) A project provides no additional irrigation capability until construction is complete.
- 3) Construction cost of a project accrues in equal annual installments during the construction period.

Thus, the following equations represent the process of planning for a new irrigation development project:

IRRNU = BUDI/COSTI (R3)  
 CALL INPIPE (IRRIG, IRRNU, IRRDELA) (R4)  
 CALL UNICOST (JRRCOST, BUDI, IRRDELA) (R5)

where: IRRNU = the amount of water to be provided by a given new irrigation development project ( $m^3$ /year) [ $m^3$ = cubic meters].

BUDI = the total amount budgeted for the (entire) cost of the project (\$).

COSTI = the cost per  $m^3$  per year of the irrigation development project (\$/ $m^3$ /year).

CALL INPIPE invokes a computer subroutine which delays the appearance of the new irrigation water until a certain number of iterations (equal to the number of years needed for construction of the project) has occurred.

IRRIG = a variable which is part of the INPIPE subroutine.

IRRDELA = the number of years required for this particular project to be completed (years).

CALL UNICOST invokes a computer subroutine which keeps track of both the total annual costs for all irrigation development projects underway at a given time, and the number of years remaining until each project is completed.

JRRCOST = a variable which is part of the UNICOST subroutine.

It should be apparent that the model must also yield a figure for any new irrigation water which becomes available during the current iteration. This is done through the following equation:

IRD = OUTPIPE (IRRIG) (R6)

where: IRD = irrigation development rate; the amount of water becoming available as a result of the completion of one or more irrigation development projects during the current iteration ( $m^3$ /year).

OUTPIPE (IRRIG) invokes a computer subroutine which determines, from stored information on earlier irrigation development project planning decisions, how much new water becomes available during the current iteration.

The following equations provide for the determination of how much irrigated land will be available and for the allocation of part of that land to wheat production. The equations also allow for the assumption that irrigated land resulting from recent irrigation development projects should tend to be double-cropped. Thus, we keep track of both the actual land devoted to wheat and the cropped land devoted to wheat, where the latter is the number of physical hectares times the average number of crops grown on them per year.<sup>16</sup>

$$IRP = IRD/IRF + IRP \quad (R7)$$

$$IRRWEAT = NUCROP*IRP*P2 + OLDCROP*IRA*P3 \quad (R8)$$

$$TOTWEAT = RFAWEAT + IRRWEAT \quad (R9)$$

$$LUC = TOTRFA + IRA + IRP \quad (R10)$$

$$LCW = RFAWEAT + IRA*P3 + IRP*P2 \quad (R11)$$

$$IRRTOT = IRA + IRP \quad (R12)$$

where: IRP = new irrigated land resulting from the completion of irrigation-development projects (hectares).

IRR = the amount of water required for very high yield wheat production assuming double-cropping ( $m^3$ ).

IRRWEAT = total irrigated cropped land allocated to wheat production (hectares).

NUCROP = cropping ratio (ratio of cropped land to physical land) for new irrigated land (dimensionless).

OLDCROP = cropping ratio for old irrigated land (land irrigated but not as part of a modern irrigation development project) (dimensionless).

IRA = total old irrigated land (hectares).

P2 = proportion of new irrigated land to be allocated to wheat production (dimensionless).

P3 = proportion of old irrigated land to be allocated to wheat production (dimensionless).



TOTWEAT = total cropped land allocated to wheat production  
(hectares)

LUC = total physical land under cultivation (hectares)

LCW = total physical land allocated to wheat production  
(hectares)

IRRTOT = total irrigated physical land under cultivation  
(hectares)

#### B. THE MODERNIZATION COMPONENT

As we have noted so often in this paper, the development of a single input (e.g., water) is not by itself sufficient to bring about increased agricultural production. Instead, a number of separate (but closely interrelated) modernizing inputs are required, including fertilizers, farm machinery, improved seed varieties, etc. In order to explore the impact of these modernizing inputs upon agricultural production, a "modernization" component has been built into the model. This component focuses specifically on the impact of two such inputs on the production of wheat in the five countries: fertilization and mechanization. The principal output of this component is a measure of productivity (yield per hectare).

There are two main influences on productivity of land if water is adequate. They are the level of fertilization and the level of mechanization. The levels of usage of fertilizer and modern machinery and the effects of those levels of usage enter into this component through the following equations:

$$RFERT = BUDF/GVPFERT \quad (M1)$$

$$FERTA = 1000 * RFERT/IRRWEAT \quad (M2)$$

$$RMECH = BUDM/GVPMech \quad (M3)$$

$$ATP = (1 - (1/WEAROUT)) * ATP + RMECH \quad (M4)$$

$$POWU = ATP/IRRTOT \quad (M5)$$

$$YPHM = \min(YLDF(FERTA), YLDM(POWU)) \quad (M6)$$

$$YPH = (YPHT * RFAWEAT + YPHM * IRRWEAT) / LCW \quad (M7)$$

where: RFERT = the amount of fertilizers obtained by the government for a given year (metric tons).

BUDF = the amount budgeted (and spent) by the government for purchase of fertilizers during a given year (\$).

GVPFERT = the government's price of fertilizer. This is a weighted price for nitrogen, phosphate, and potash fertilizers purchased in the proportion 5:2:2 (\$/metric ton).

FERTA = the fertilizer application rate (kg/hectare).

IRRWEAT = the amount of irrigated cropped land devoted to wheat (see earlier definition in Resource Allocation component) (hectares).

RMECH = the amount of mechanization obtained by the government for a given year (hp).

BUDM = the amount budgeted (and spent) by the government for the acquisition of new and replacement tractors during a given year (\$).

GVPMECH = the government's price of farm tractors (\$/hp).

ATP = available tractor power. This is the total of all available operative tractors (hp).

WEAROUT = the average expected useful life of a tractor (years).

POWU = the average rate of power (tractor) utilization (hp/hectare).

IRRTOT = total irrigated land (hectares).

YPHM = yield per hectare (modern). This is the average yield for land farmed with modern methods (kg/hectare).

MIN( ) is a function which selects the lowest of the values enclosed in parentheses. Here it selects either YLDF (FERTA) or YLDM (POWU), whichever is lower.

YLDF (FERTA) = a function which relates the wheat yield to fertilizer application rate, assuming adequate water and mechanization (See Appendix I) (kg/hectare).

YLDM (POWU) = a function which gives the wheat yield possible with any given level of mechanization, assuming adequate water and fertilization (See Appendix II) (kg/hectare).

YPH = average overall yield for wheat (kg/hectare).

YPHT = yield per hectare (traditional). This is the average yield on rainfed land with traditional methods (kg/hectare).

LCW = total land in wheat production (hectares).

With regard to the above equations, two points should be kept in mind. First, there is no provision for the accumulation of fertilizers over time. Such a provision may easily be added if it should turn out to be needed. However, we assume that because of the low quality of the soils in these countries farmers will use all of the fertilizer they are able to get. Second, we assume that the productivity of traditional (rainfed) land will remain constant throughout the simulation run since so little of that land is susceptible to modern capital-intensive methods. This is the case for wheat in Saudi Arabia, at least.

### C. THE PRODUCTION COMPONENT

The third component in our model deals with production and with the returns (or losses) to the farmers and to the government as a result of wheat production activities. The following set of equations makes up this component:

$$YLD = .001 * YPH * LCW \quad (P1)$$

$$OUTC = PCON * YLD \quad (P2)$$

$$OUTE = YLD - OUTC \quad (P3)$$

$$\text{GVCOST} = (\text{GVPFERT} - \text{FMPFERT}) * \text{RFERT} + (\text{GVPMECH} * \text{RMTECH} - \text{FMPMECH} * \text{ATP}) * (\text{LCW} - \text{RFAWEAT}) / (\text{IRP} + \text{IRA}) \quad (\text{P4})$$

$$\text{TINC} = \text{DMPRICE} * \text{YLD} - \text{FMPFERT} * \text{RFERT} - \text{FMPMECH} * \text{ATP} \quad (\text{P5})$$

$$\text{INCPC} = \text{TINC} / \text{SALF} \quad (\text{P6})$$

$$\text{INCH} = \text{TINC} / \text{LCW} \quad (\text{P7})$$

$$\text{LABP} = \text{YLD} / \text{SALF} \quad (\text{P8})$$

where: YLD = total production actually achieved (metric tons).

OUTC = quantity of wheat produced which is allocated to domestic consumption (metric tons).

PCON = proportion of wheat production allocated to domestic consumption. This is a policy variable expressed as a decimal value between 0 and 1.0 (dimensionless).

OUTE = quantity of wheat produced which is available for export (metric tons).

GVCOST = net cost to the government of subsidizing modern wheat farming practices through provision of fertilizer and machinery (\$).

FMPFERT = farm price of fertilizer. This is the price paid by the farmer (\$/metric ton).

FMPMECH = farm price of mechanization. This is the cost to the farmer of using 1 hp for one year (\$/hp-year).

TINC = total income (net) for all farmers (\$).

DMPRICE = domestic price of wheat (price received by farmers) (\$/kg).

INCPC = average net income from wheat per agricultural person (\$/man).

SALF = size of the agricultural labor force engaged in growing wheat.

INCH = average net income from wheat per hectare of land used in wheat production (\$/hectare).

LABP = a measure of labor productivity: the average yield per person engaged in growing wheat (kg/man).

#### D. CONSUMPTION/DEMAND COMPONENT

This final component in our proposed model essentially represents a budgetary accounting mechanism. It takes information on production outputs (from the production/marketing component) and computes the values for several variables measuring the overall performance of the production process being modeled. Put more simply, the purpose of this component is to compute the final set of variables comprising the performance vector. These variables include the value of crop exports (Equation C1) and the demand for food imports (Equation C3).

$$\text{VALEXP} = \text{WP} * \text{OUTE} \quad (\text{C1})$$

$$\text{DWHEAT} = \text{BASED} * (\text{POPI} / 100 + \text{ELAST} * (\text{INDXPCE} / \text{POPI} - 1.0) \quad (\text{C2})$$

$$\text{IMPORT} = \text{DWHEAT} - \text{OUTC} \quad (\text{C3})$$

$$\text{POPI} = (1 + \text{POPGR}) * \text{POPI} \quad (\text{C4})$$

where: VALEXP = total value of wheat exported (\$).

WP = world price for wheat (\$/metric ton).

DWHEAT = consumption demand for wheat for the current year  
(See Asfour, p. 25) (metric tons).

BASED = consumption demand for food in a base year  
(metric tons).

POPI = index of population for the current year relative to the  
base year (dimensionless).

ELAST = elasticity coefficient of demand for wheat (dimensionless).

INDXPCE = index of total private consumption expenditure for  
the current year.

IMPORT = imports of wheat required during the current year in  
order to meet demand.

POPGR = annual proportional increase in population (expressed  
as a decimal value) (dimensionless).

## E. DISCUSSION

Perhaps the most critical change present in this revised model of the agricultural sector is that of ignoring the microeconomic behavior of the individual farmer. It is assumed that the adoption of modern farming methods will occur only when heavy subsidization of the required inputs and intensive efforts by agricultural extension teams are present. This seems reasonable, since the adoption of modern methods as a result of extension work alone has been minimal in Saudi Arabia.<sup>17</sup> In addition, since there exists no true country-wide price and/or transport system, the price paid to the farmer in a subsidized program will likely be controlled (either directly or indirectly) by the government.

Thus, in our model we assume that:

- a) all fertilizer is bought by the government and resold to the farmers;
- b) all tractors and other mechanized equipment is bought and maintained by the government, and rented to individual farmers;<sup>18</sup> and
- c) the government pays the total cost of constructing and operating water development projects.

We also assume that the government is willing to absorb a reasonable loss in subsidizing the production of wheat in order to lessen the country's dependence on imports.

Thus our model may be seen to be structured almost totally around the policy-maker. The costs involved are costs to the government. The computed average income per person engaged in wheat production, for instance, is really more a social indicator for the policy-maker than a measure of earned income and economic strength in a free market sector. The government controls the farmers' incomes through setting prices on

wheat, fertilizer, and machinery. And so on.

To the extent that this image of the agricultural sector in Saudi Arabia is correct, the model may not be too far off the mark. If these simplifying assumptions are found to be unwarranted, however, then considerably more detail may be necessary in the model. Given the difficulty of obtaining reliable (let alone extensive) data on Saudi Arabian agriculture, however, this model seems a reasonable beginning.



## APPENDIX I

### YIELD RESPONSE TO FERTILIZER ASSUMING ADEQUATE WATER AND LEVEL OF MECHANIZATION

The function used in this model for giving the yield response to level of fertilization (assuming water and mechanization level are sufficient) is necessarily a hypothetical one. The following comments present the assumptions made in hypothesizing this particular response curve.

First, it was assumed that the shape of the curve would be one in which the slope was steep initially, was less steep and approximately linear through a middle range, fell to zero at some point of maximum possible yield was passed through, and became increasingly negative beyond that point.<sup>1</sup>

Second, the slope of the approximately linear portion of the curve was taken to be 15 kg/kg. This figure was arrived at on the basis of estimates indicating that approximately 2 pounds of nitrogen and .8-1.0 pounds each of  $P_2O_5$  and  $K_2O$  would be needed per bushel of wheat produced.<sup>2</sup>

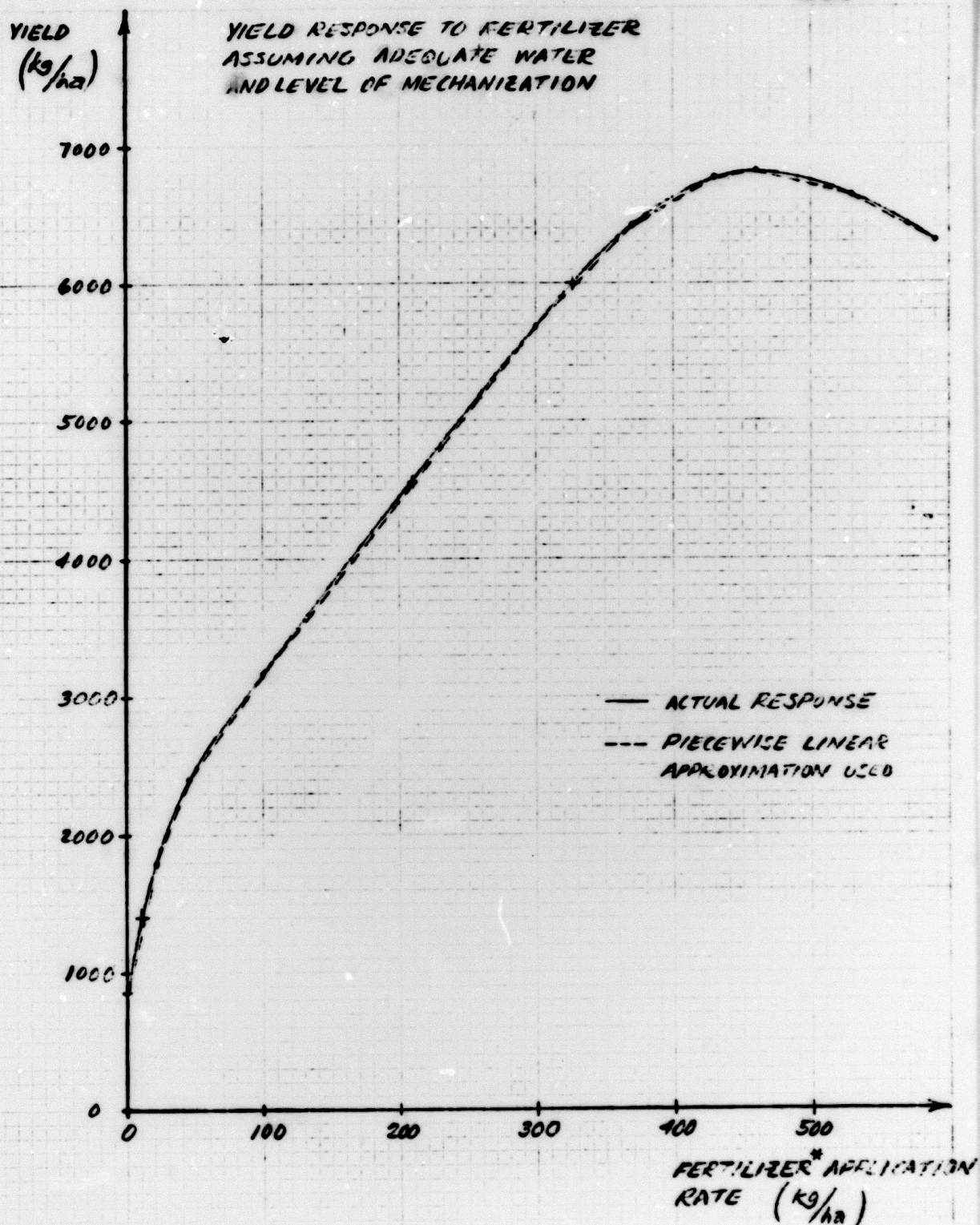
Third, the point of maximum yield was assumed to be slightly greater than the 6720 kg/ha shown in Table 6.3 of Seifert, et al (p. 60). No assertion is made here that this is an accurate estimate of the point of maximum yield; it is simply a point of relatively high yield arbitrarily selected for use in order to permit testing the model's general behavior.

Fourth, points on the low end of the curve were selected on the basis of an assumption of 1400 kg/ha with very little fertilizer and

870 kg/ha with no fertilizer. The first figure comes from Clawson, Landsberg, and Alexander (p. 299). The second is estimated from the same work (p. 228), and is used with the assumption that yields in years from 1951-1957 reflect a virtually zero level of fertilizer utilization.<sup>3</sup>

Fifth, the use of seed varieties responsive to high fertilization levels is assumed.

Once again, the response function shown in Figure A-I is hypothetical, but its general shape should be correct, and the curve itself may be easily changed on the basis of more accurate data.



\* FERTILIZER ASSUMED TO BE NITROGEN,  $P_2O_5$ ,  
AND  $K_2O$  IN RATIO 5:1:1

A-I FOOTNOTES

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<sup>1</sup>See United Nations Food and Agriculture Organization, The State of Food and Agriculture (1968), pp. 90-91 and especially Table III-5. Note that Table III-5 either assumes zero output if no fertilizer is applied or else has incorrect figures for total crop output. Since the table is hypothetical and meant only to illustrate the text, however, it was assumed that these errors should not prevent the inference concerning the shape of the fertilizer response curve underlying the table.

<sup>2</sup>See Clawson, et al, p. 145. See also United Nations, FAO, p. 89. These figures also provide the basis for the assumed 5:2:2 (N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O) ratio.

<sup>3</sup>See also Asfour, pp. 62-63 and 73-74. Approximately 10 kg/ha of fertilizer was used in Saudi Arabia in 1961.

## APPENDIX II

### MECHANIZATION CONSTRAINT ON YIELD RESPONSE TO FERTILIZER ASSUMING ADEQUATE WATER

The function (shown in Figure A-2) for mechanization level required to reach various production levels is even more conjectural than that for yield response to fertilizer. It is assumed here that mechanization is required if high yields are to be obtained; the process of obtaining such high yields requires many more operations (irrigation, fertilization, mechanical harvesting, tillage, etc.) than are required in traditional agriculture. Moreover, high levels of mechanization should permit double-cropping in Saudi Arabia.<sup>1</sup>

Exactly what levels of mechanization are required for particular levels of output (assuming adequate water and fertilizer), however, is highly speculative. Estimates of the need for various levels of mechanization are couched in phrases such as ". . . underpowered at 0.5 horsepower per hectare, and that 1.0 horsepower per hectare would represent overpowering. . ."<sup>2</sup>

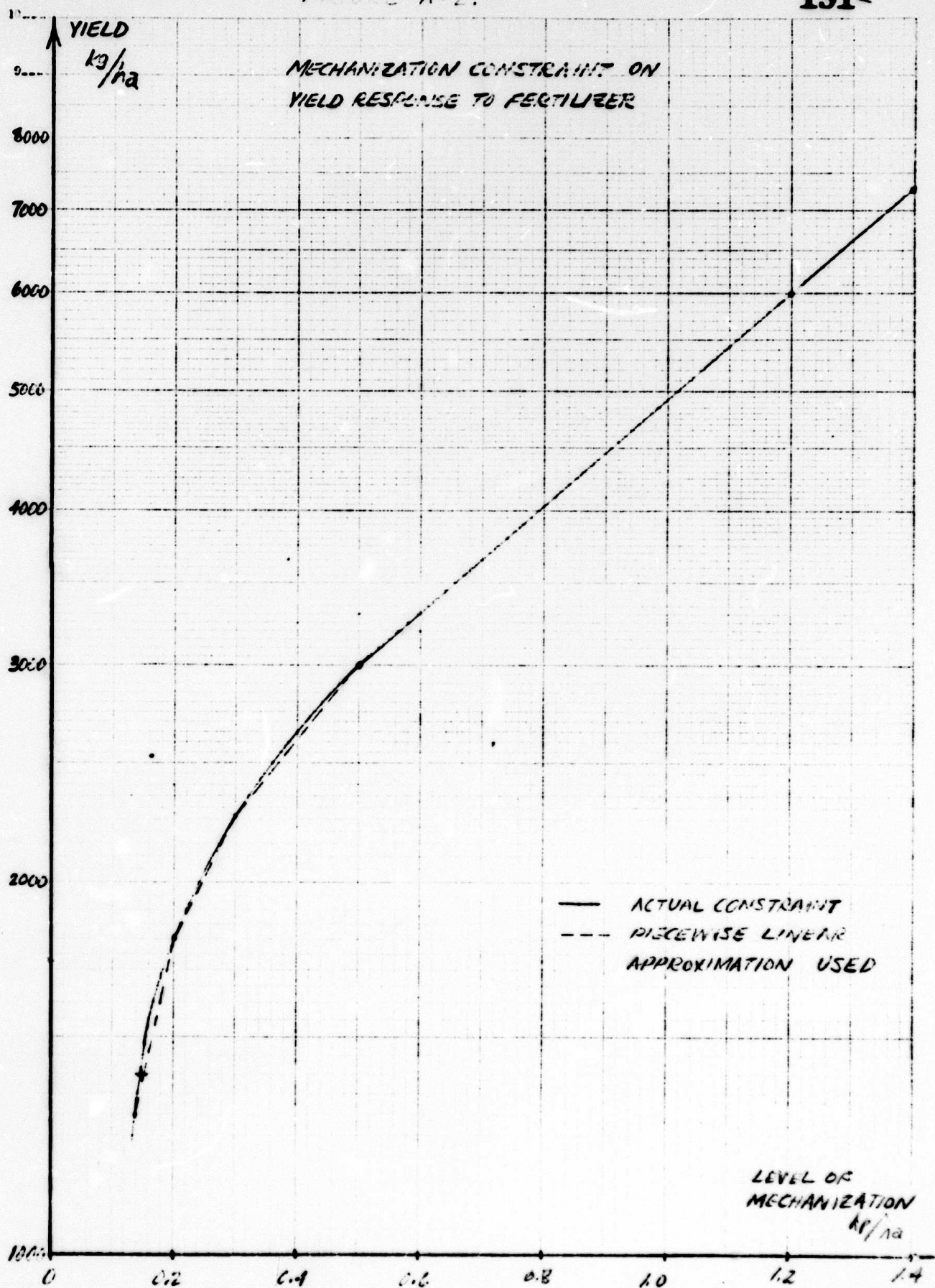
The function used in the model at this time takes its shape from a plot of hp/ha vs. average aggregate yield of major food crops for several nations.<sup>13</sup> Few nations show power utilization levels greater than 1.0 hp/ha, but a level of 1.0 hp/ha generally is associated with only 2300-3400 kg/ha yields. Yields of 5000<sup>+</sup> kg/ha are shown only for nations using 1.7-2.1 hp/ha.

Hence for this effort a power utilization level of 1.2 hp/ha was arbitrarily chosen as necessary to achieve a 6000 kg/ha yield, 0.5 hp/ha for a 3000 kg/ha yield, and 0.2 hp/ha for an 1800 kg/ha yield.

Mechanization and fertilizer are treated as mutual constraints; a high level of fertilization cannot produce a high yield if mechanization sufficient to permit efficient performance of other required operations is not available, and mechanization is of limited utility without fertilizer.

As is the case for the fertilizer response function, the mechanization constraint function should be revised when better data are obtained.







A-II FOOTNOTES

<sup>1</sup>See Seifert, et al, p. 63.

<sup>2</sup>Clawson, Landsberg, Alexander, p. 149.

<sup>3</sup>United Nations FAO, p. 93.

FOOTNOTES

- <sup>1</sup>We refer specifically to the following five countries: Algeria, Iran, Iraq, Libya, and Saudi Arabia.
- <sup>2</sup>Clawson, Marion, Hans Landsberg and Lyle Alexander (1971) The Agricultural Potential of the Middle East. New York: American Elsevier Publishing Co., Inc. p. 2.
- <sup>3</sup>Clawson, Landsberg and Alexander, p. 37.
- <sup>4</sup>Ibid.
- <sup>5</sup>Clawson, Landsberg and Alexander, p. 115.
- <sup>6</sup>Ibid.
- <sup>7</sup>As Clawson, Landsberg and Alexander have indicated, it is estimated that the costs for producing groundwater from pumped deep wells runs between \$250 and \$370 per acre-foot (1971, p. 115). In contrast, Fried Edlund (1971) suggest that with the development of a large-scale single purpose plant based on oil or gas, the cost of desalination could be brought down to around 25 to 35 cents per 1000 gallons, which is equivalent to \$81 to \$114 per acre-foot.
- <sup>8</sup>The use of groundwater is an even more practical alternative in Libya, where along with the continued search for oil has come, in recent years, the discovery of bountiful sources of underground water.
- <sup>9</sup>Clawson, Landsberg and Alexander, p. 4.
- <sup>10</sup>Brenner, Y.S. (1971) The Economics of Agricultural Development. Ithaca, N.Y.: Cornell University Press, p. 50.
- <sup>11</sup>Clawson, Landsberg and Alexander, p. 41.
- <sup>12</sup>Schultz, T.W. (1964) Transforming Traditional Agriculture New Haven: Yale University Press, p. 33.
- <sup>13</sup>Ibid.
- <sup>14</sup>Clawson, Landsberg and Alexander, p. 111
- <sup>15</sup>By a "building block" approach, we refer specifically to the modeling approach developed by Glen Johnson, et al, namely "the generalized system simulation approach."

<sup>16</sup>It is important to keep track of this distinction (between cropped and physical land).

<sup>17</sup>See Seifert, et al, pp. 54-55, and Asfour, pp. 73-74.

<sup>18</sup>See Asfour, p. 73, Saudi Arabian Monetary Agency, p. 49, and Saudi Arabia Central Department of Statistics, pp. 72-73.

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HUMAN RESOURCES  
IN SAUDI ARABIA

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# Human Resources in Saudi Arabia

## INTRODUCTION - Part I

Human resources in Saudi Arabia are modeled here as a flow process (see R.E. Wendell, August 1974). The flow process "sees" the population of Saudi Arabia at any given time as divided into a collection of mutually exclusive and exhaustive categories. Persons "flow" from one category to another over a time horizon according to specified transitional constants. To illustrate, a person might move from intermediate education to secondary education with a probability of .2, whereas probability of moving from secondary to intermediate might be .0. A matrix containing all transition probabilities, called the total transition matrix, together with a baseline vector of numbers of persons within each category generates vector descriptions of Saudi human resources.

### Notation:

$t$  = time index

$p^t$  = population at  $t$

$n$  = number of categories in human resources description vector

$T^t$  = an  $(n \times n)$  matrix of transition constants. This matrix will be assumed to be filled with real numbers rather than functions of time.

$M^t$  = an  $(n \times 1)$  vector description of Saudi human resources at  $t$ .  
Note that the sum of entries equals population at  $t$ .

### Basic Relationship:

$$M^{t+1} = T^t * M^t$$

Vector description of human resources at  $t+1$  equals total transition matrix multiplied by vector description at  $t$ .

Discussion:

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Several tasks present themselves. One is to select the categories which make up the vector description of the human resources sector. This problem was addressed in a pragmatic manner. Categories were chosen, in part, according to the existence of data. Another consideration in the selection of these categories was that we would like to be able to address questions of industrial, oil, and agricultural expansion with these categories. The vector selected,  $m_1, \dots, m_{15}$ , is:

- $m_1$  = persons in unstructured pool
- $m_2$  = " " elementary school
- $m_3$  = " " intermediate school
- $m_4$  = " " secondary school
- $m_5$  = " " teacher training school
- $m_6$  = " " technical and adult school
- $m_7$  = " " universities (Saudi and non-Saudi)
- $m_8$  = petroleum wage earners
- $m_9$  = non-petroleum wage earners
- $m_{10}$  = civilian governmental employees
- $m_{11}$  = military governmental employees
- $m_{12}$  = non-industrial wage earners
- $m_{13}$  = self-employed non-agricultural
- $m_{14}$  = self-employed agricultural
- $m_{15}$  = persons having moved through human resources

The next problem is to collect data to estimate a baseline  $M$  vector and transition constants. Collection of data and specification of a baseline  $M$  vector are in Part 2. The estimation of transition constants is found in Part 3.

# BASIC DATA - Part II

The second section of "Human Resources in Saudi Arabia" will consist of the data used for the analysis. There are two broad kinds of data in the analysis. First, there are primary or direct data. These are data reported in some source, such as a statistical abstract. Secondly, there are derived data. These are data generated by The Project for Theoretical Politics. In the following exposition, direct data will be presented first, followed by derived data.

The first bit of data is about the Saudi Arabian educational system. Other bits of primary data include work force division sizes as a percentage of the total work force and United Nations population estimates. These pieces of direct information are used to generate Table IV.

Table I Educational Data

<u>Year</u>	<u>m2</u>	<u>m3</u>	<u>m4</u>	<u>m5</u>	<u>m6</u>	<u>m7</u>	<u>TOTAL</u>
69/70	383,644	43,455	8,917	9,631	50,521	14,604	510,429
68/69	252,207	33,547	6,913	2,173	44,932	12,416	457,570
67/68	234,726	30,676	5,834	2,093	44,134	10,903	415,115
66/67	212,674	20,279	3,428	3,438	45,913	9,399	295,131
65/66	193,140	18,497	2,876	5,245	36,877	7,917	264,552
64/65	174,514	14,832	2,484	7,556	37,407	6,479	243,272
63/64	156,780	13,768	2,290	6,876	28,619	5,177	213,510
62/63	139,338	11,148	1,997	5,576	25,440	4,601	188,100
61/62	122,905	9,229	1,547	4,395	19,570	3,391	
60/61	104,203	7,875	1,136	3,497	11,184	2,899	

Data for this table are taken from the Saudi Arabian Statistical Abstract 1970.

Table II Manpower Data

<u>Manpower Category</u>	<u>Percentage of Total Work Force</u>
Petroleum wage earners	1.0
Non-petroleum, industrial wage earners	.8
Civilian governmental employees	9.0
Military employees	6.0
Non-industrial wage earners	8.2
Self-employed, non-agricultural	1.0
Self-employed, agricultural	74.0
TOTAL	100.0

	<u>Number of Persons</u>	
	<u>1964</u>	<u>1972</u>
Private		1,140,000
Public		160,000
TOTAL	1,000,000	1,300,000

Category percentages are taken from Rugh, 1973<sup>1</sup>. Total labor estimates fall between those in the Hammad dissertation and the Rugh article.

Table III Population<sup>2</sup>

	<u>1963</u>	<u>1972</u>
Population	6,420,000	8,200,000

<sup>1</sup> "Emergence of a New Middle Class in Saudi Arabia" The Middle East Journal V. 27, No. 1.

<sup>2</sup> United Nations Demographic Yearbook 1973

Derived Constants

Granted the two point fixes on the labor force an annual growth constant of 1.03 fits available data. Similarly, a constant of 1.028 is selected for population data. Primary data, together with these constants yield a derived table, Table IV.

Table IV

<u>Year</u>	<u>Population</u>	<u>Education</u>	<u>Labor</u>	<u>Unstructured Pool</u>
1963	6,420,000	188,100*	970,874	5,261,026
1964	6,597,000*	213,510*	1,000,000	5,383,490
1965	6,781,000	243,272*	1,030,000	5,537,490
1966	6,968,000	264,552*	1,060,900	5,642,548
1967	7,164,000	295,131*	1,092,727	5,776,142
1968	7,359,000	415,115*	1,125,509	5,818,376
1969	7,563,000	457,570*	1,159,274	5,946,156
1970	7,773,000	510,429*	1,194,052	6,068,519
1971	7,988,000	--	1,229,874	--
1972	8,200,000*	--	1,250,000	--
1973	8,437,000	--	1,304,773	--

\* indicates direct data

Table IV was generated by (1) establishing entries for the population column by means of applying the population growth constant to U.N. data (page 4), (2) transcribing educational data (3) generating labor data by means of estimates for 1964 and 1972 together with labor force growth constant (4) and finally subtracting education and labor sectors of the population from the total population. The unstructured pool of Table IV is, as the name suggests, a body of Saudis about whom we know little. Ignorance of such vast proportions are mitigated to some extent by the supposition that roughly half of the pool consists of women. Since women in Saudi society are systematically excluded from labor and to a lesser extent from education,

ignorance as to the status of Saudis with respect to our model of that society is not so great as it might appear.

From Tables I, II, and IV, a baseline data vector for 1970 is constructed.

$$M^{1970} = \begin{bmatrix} 6,068,519 \\ 383,644 \\ 43,455 \\ 8,917 \\ 9,631 \\ 50,521 \\ 14,604 \\ 11,940 \\ 9,552 \\ 107,465 \\ 71,640 \\ 97,912 \\ 11,941 \\ 883,600 \\ 0 \end{bmatrix} *$$

\*See page 2, Part I

### CONSTRUCTION OF TRANSITION CONSTANTS - Part III

Recall the basic relationship of the flow model,  $M^{t+1} = T * M^t$ . For the purpose of vector and transition probability estimation the human resources module decomposes into (1) unstructured pool; (2) educational system; and (3) labor force.

$$\begin{bmatrix} \text{pool} \\ \text{-----} \\ \text{education} \\ \text{-----} \\ \text{labor} \end{bmatrix}^{t+1} = \begin{bmatrix} A1 & A2 \\ A7 & A3 & A4 \\ A8 & A6 & A5 \end{bmatrix} * \begin{bmatrix} \text{pool} \\ \text{education} \\ \text{labor} \end{bmatrix}^t$$



Transition Sub-blocks

$A_1$  and  $A_2$  together give us  $ml^{t+1}$  as a function of  $m^t$ . Because this is an unstructured pool of persons it is assumed that a growth constant is acceptable. That is to say that  $A_1$  will be a constant and  $A_2$  a vector filled with zeros.  $ml^{t+1}$  is modeled as a function of only  $ml^t$ .

- $A_3$  - Is intra-educational transitions. Here flow through the Saudi educational system is modeled.
- $A_4$  - Is labor to education transition. The constants for moving from labor back into education are here.
- $A_5$  - This is the intra-labor transition matrix. Here constants for moving from one sector of labor to another are given.
- $A_6$  - Education to labor matrix. These constants model flows from the Saudi educational system into the labor sector.
- $A_7$  - This block gives movement from the unstructured pool at  $t$  into the educational system at  $t+1$ .
- $A_8$  - This block models direct movement from the unstructured pool at  $t$  into the labor force at  $t+1$ .

Table V

## Category Data Used for Estimation

	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12	m13	m14
1965	5,537,490	174,514*	14,832*	2,484*	7,556*	37,407*	6,479*	103,000	8,000	92,700	61,800	84,460	10,300	762,200
1966	5,642,548	193,140*	18,497*	2,876*	5,245*	36,877*	7,917*	106,090	8,240	95,481	63,650	80,994	10,609	785,056
1967	5,776,142	212,674*	20,279*	3,428*	3,438*	45,913*	9,399*	109,273	8,487	98,345	65,500	89,604	10,927	808,620
1968	5,318,376	234,726*	30,076*	5,834*	2,093*	44,134*	10,903*	112,551	8,742	101,296	67,530	92,922	11,255	832,900
1969	5,946,156	252,207*	33,547*	6,913*	2,173*	44,932*	12,416*	115,927	9,004	104,335	69,560	95,060	11,593	857,900
1970	5,068,519	268,689*	38,930*	8,479*	9,631*	50,521*	14,604*	119,405	9,274	107,465	71,640	97,912	11,941	883,600

\*indicates direct data

Columns m8, . . . , m14 are generated from percentages, Table II and, from labor category entries, Table IV.  
 m1 is direct from Table IV.

### Estimation Procedure for Transition Constants

The construction of transition constants that provide a reasonable representation of the data in Table V and yield yearly vector predictions is the task at hand. Procedures with various error minimization techniques and known statistical properties are available. Rather than blindly apply such techniques knowledge of the Saudi system is modeled into the total transition matrix, followed by error minimization procedures. To illustrate, we go through the teacher training institutions estimation,  $m_5$ . It is known that these institutions are of secondary level. Because of this,  $m_5$  is assumed to be a function of itself, i.e., those who have begun the teacher training program and have neither matriculated nor dropped out, and of intermediate education,  $m_3$ . It is expected that people don't jump from elementary to secondary education. Accordingly,  $m_2$  is given zero for a transition constant. Similar reasoning holds for the unstructured pool. We don't expect people to back up in the educational system resulting in the zero transition from universities. Although people might move from one secondary sort of education to another, it is not modeled into our transition matrix, hence zeros for  $m_4$  and  $m_6$ . Finally, we don't allow movement from the labor pool back to teacher training. Such movement is modeled into adult education.

In the above style of reasoning, free variables are selected according to intuition and conventional wisdom. A final transition constant is computed so that the model will match data sequences for each category. This is accomplished by computing absolute deviations, summing deviation, averaging the sum and dividing by averaged input pool size.

e.g.,  $m_i(t+1) = x_1(m_i t) + x_2(mj t)$

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Time	Size of $m_i$ category	$x_1 m_i(t)$	Error
t+1	$n_1$	$x_1 n_2$	$ln_1 - x_1 n_2$ 1
t	$n_2$	$x_1 n_3$	$ln_2 - x_1 n_3$ 1
t-1	$n_3$	$x_1 n_4$	$ln_3 - x_1 n_4$ 1
t-2	$n_4$	$x_1 n_5$	$ln_4 - x_1 n_5$ 1
t-3	$n_5$	$x_1 n_6$	$ln_5 - x_1 n_6$ 1
t-4	$n_6$	$x_1 n_7$	$ln_6 - x_1 n_7$ 1

$x_2 = \text{average error/average } mj$

$\Sigma$  of error  
average error  
average of  $mj$

$m_1$ : estimation of unstructured pool

As already mentioned, this category is treated as if  $m_1^{t+1}$  is a function of  $m_1^t$ . The following procedure for estimation was used: the absolute value of yearly data (see Table IV) minus average site of unstructured pool was taken, summed and divided by its n. This number, an average absolute deviation was divided by average site of pool yielding a constant.

Year	Data	Average Size	Deviation
1964	5,383,490	5,684,034	300,544
1965	5,537,490	5,684,034	146,544
1966	5,642,548	5,684,034	41,486
1967	5,776,142	5,684,034	92,168
1968	5,819,376	5,684,034	134,342
1969	5,946,150	5,684,034	262,116
1970			

$162,867 = .022$   
 $m_1^{t+1} = 1.022 m_1^t$

Total Deviation = 977,200  
Total/N = 162,867

m2: elementary education

It was decided that  $m2^{t+1} = f(m1^t, m2^t)$ . Furthermore, the form and content were chosen as:

$$m2^{t+1} = .75m2^t + x_1m1^t + c_2$$

.75 was chosen due to the nature of Saudi education. It is patterned on the U.S. scale of 1-6 elementary followed by three years of intermediate and secondary, respectively.

1970 was the first year for which female statistics are available.

Therefore, constants are based on male only data. Baseline data, however, includes female students.

<u>t+1</u>	<u>m2<sup>t+1</sup></u>	<u>x<sub>1</sub>m2<sup>t</sup></u>	<u>Error</u>
1970	268,689	189,155	79,534
1969	252,207	176,045	76,162
1968	234,726	159,506	75,220
1967	212,674	144,855	67,819
1966	193,140	130,889	66,241
1965	174,514	117,585	56,929

SUM OF ERROR = 421,905

AVERAGE ERROR = 70317.5

AVERAGE OF m1 = 5,684,034

$x_2 = 70317.5 / 5,684,034 = .01237$

m3: intermediate education

$m_3^{t+1} = x_1 m_3^t + x_2 m_2^t$  is an assumed relationship. .5 is picked for  $x_1$ .  $x_2$  is derived.

<u>t+1</u>	<u>m3<sup>t+1</sup></u>	<u>x<sub>1</sub>m3<sup>t</sup></u>	<u>Error</u>
1970	38,930	16,774	22,156
1969	33,547	15,338	18,209
1968	30,076	10,140	20,536
1967	20,279	9,249	11,030
1966	18,497	7,416	11,081
1965	14,832	6,884	7,948

SUM OF ERROR = 90,960

AVERAGE ERROR = 15,160

SUM OF ELEMENTARY = 1,224,041

AVERAGE ELEMENTARY = 204,007

$x_2 = 15,160 / 204,007 = .075$

m4: secondary education

$m_4^{t+1} = x_1 m_4^t + x_2 m_3^t$  is the assumed relationship. Picking .5 for  $x_1$ ,  $x_2$  is derived.

<u>t+1</u>	<u>m4<sup>t+1</sup></u>	<u>x<sub>1</sub>m4<sup>t</sup></u>	<u>Error</u>
1970	8,479	3,457	5,022
1969	6,913	2,917	3,996
1968	5,834	1,714	4,120
1967	3,428	1,438	1,990
1966	2,876	1,242	1,034
1965	2,484	1,145	1,339

SUM OF ERROR = 18,101

AVERAGE ERROR = 3016.8

SUM OF m3 = 131,599

AVERAGE m3 = 21,933

$$x_2 = 3016.8 / 21,933 = .1375$$

m5: teacher training schools

$m_5^{t+1} = x_1 m_5^t + x_2 m_3^t$  is the assumed relationship. .5 is picked for  $x_1$ ,  $x_2$  is derived.

<u>t+1</u>	<u>m5<sup>t+1</sup></u>	<u>x<sub>1</sub>m5<sup>t</sup></u>	<u>Error</u>
1970	9,631	1,087	8,544
1969	2,173	1,047	1,126
1968	2,093	1,719	374
1967	3,438	2,623	815
1966	5,245	3,778	1,467
1965	7,556	3,438	4,118

SUM OF ERROR = 16,444

AVERAGE ERROR = 2740.7

SUM OF m3 = 131,599

AVERAGE m3 = 21,933

$$x_2 = 2740.7 / 21,933 = .1249$$



m6: technical and adult school

21.5

$m6^{t+1} = x_1 m6^t + x_2 m3^t + x_3 m1^t$  is the assumed relationship.

$x_1$   $x_1$  is .5 and  $x_2$  is chosen as .1.  $x_3$  is derived.

<u>t+1</u>	<u>m6<sup>t+1</sup></u>	<u>x<sub>1</sub>m6<sup>t</sup></u>	<u>x<sub>2</sub>m3<sup>t</sup></u>	<u>Error</u>
1970	50,521	22,466	3,355	24,700
1969	44,932	22,067	3,068	19,797
1968	44,134	22,957	2,028	19,149
1967	45,913	18,439	1,850	25,624
1966	36,877	18,704	1,483	16,690
1965	37,407	14,310	1,377	21,720

SUM OF ERROR = 127,680

AVERAGE ERROR = 21,280

AVERAGE m1 = 5,684,034

$x_3 = 21,280 / 5,684,034 = .0037$

m7: university

$m7^{t+1} = x_1 m7^t + x_2 m6^t$  is the assumed relationship.  $x_1$  and  $x_2$  are picked at .7 and .1, respectively.  $x_3$  is derived.

<u>t+1</u>	<u>m7<sup>t+1</sup></u>	<u>x<sub>1</sub>m7<sup>t</sup></u>	<u>x<sub>2</sub>m4<sup>t</sup></u>	<u>Error</u>
1965	6,479	3,624	248	2,607
1966	7,917	4,535	288	3,104
1967	9,399	5,542	343	2,756
1968	10,903	6,579	583	3,741
1969	12,416	7,631	691	4,094
1970	14,604	10,691	848	3,065

SUM OF ERROR = 41,803

AVERAGE ERROR = 6,934

SUM OF m4 = 237,432

AVERAGE m4 = 39,572

$x_3 = 6,934 / 39,572 = .1749$

m8: petroleum wage earner

$m8^{t+1} = x_1 m8^t + x_2 m3^t + x_3 m1^t$  is the assumed relation. .9 and .01 are picked for  $x_1$  and  $x_2$ .  $x_3$  is derived.

<u>t+1</u>	<u>m8<sup>t+1</sup></u>	<u>x<sub>1</sub>m8<sup>t</sup></u>	<u>x<sub>2</sub>m3<sup>t</sup></u>	<u>Error</u>
1965	103,000	90,000	138	12,862
1966	106,090	95,481	148	10,461
1967	109,273	98,376	185	10,712
1968	112,551	98,346	203	14,002
1969	115,927	101,296	307	14,324
1970	119,405	104,334	335	14,736

SUM OF ERROR = 77,126

AVERAGE ERROR = 12,854

AVERAGE OF m1 = 5,684,034

$$x_3 = 1218.8/5,684,034 = .000214$$

m9: non-petroleum wage earners

$m9^{t+1} = x_1 m9^t + x_2 m3^t + x_3 m1^t$  is the assumed relationship. .9 and .01 are chosen for  $x_1$  and  $x_2$ .  $x_3$  is derived.

<u>t+1</u>	<u>m9<sup>t+1</sup></u>	<u>x<sub>1</sub>m9<sup>t</sup></u>	<u>x<sub>2</sub>m3<sup>t</sup></u>	<u>Error</u>
1965	8,000	6,990	111	899
1966	8,240	7,200	138	902
1967	8,487	7,416	148	923
1968	8,742	7,638	185	919
1969	9,004	7,868	203	933
1970	9,274	8,104	307	863

SUM OF ERROR = 5,439

AVERAGE ERROR = 906.5

AVERAGE m1 = 5,684,034

$$x_3 = 906.5/5,684,034 = .000159$$

m10: civilians employed by government

$$m10^{t+1} = x_1 m10^t + x_2 m4^t + x_3 m5^t + x_4 m6^t + x_5 m7^t + x_6 m1^t \text{ is}$$

the assumed relation. .9, .1, .133, .1, .067 are picked for  $x_1 \dots x_5$ , respectively.  $x_6$  is derived.

<u>t+1</u>	<u>m10<sup>t+1</sup></u>	<u>x<sub>1</sub>m10<sup>t</sup></u>	<u>x<sub>2</sub>m4<sup>t</sup></u>	<u>x<sub>3</sub>m5<sup>t</sup></u>	<u>x<sub>4</sub>m6<sup>t</sup></u>	<u>x<sub>5</sub>m7<sup>t</sup></u>	<u>Error</u>
1965	92,700	81,000	229	913	2,862	347	7,349
1966	95,481	83,430	248	1,004	3,741	435	6,623
1967	98,345	85,933	288	698	3,688	530	7,208
1968	101,296	88,511	343	457	4,591	629	6,765
1969	104,335	91,166	583	278	4,413	751	7,144
1970	107,465	96,719	691	289	4,493	832	4,441

SUM OF ERROR = 39,530

AVERAGE ERROR = 6588.3

AVERAGE m1 = 5,684,034

$$x_6 = 6588.3 / 5,684,034 = .001159$$

m11: military personnel

$$m11^{t+1} = x_1 m11^t + x_2 m4^t + x_3 m5^t + x_4 m6^t + x_5 m7^t + x_6 m1^t \text{ is}$$

the assumed relation. .9, .1, .133, .1, .067 are picked for  $x_1 \dots x_5$ , respectively.  $x_6$  is derived.

<u>t+1</u>	<u>m11<sup>t+1</sup></u>	<u>x<sub>1</sub>m11<sup>t</sup></u>	<u>x<sub>2</sub>m4<sup>t</sup></u>	<u>x<sub>3</sub>m5<sup>t</sup></u>	<u>x<sub>4</sub>m6<sup>t</sup></u>	<u>x<sub>5</sub>m7<sup>t</sup></u>	<u>Error</u>
1965	61,800	54,000	229	913	2,862	347	7,349
1966	63,650	55,020	248	1,004	3,741	435	6,623
1967	65,500	57,290	288	698	3,688	530	7,208
1968	67,530	59,000	343	457	4,591	629	6,765
1969	69,560	60,780	583	278	4,413	751	7,144
1970	71,640	62,600	691	289	4,493	832	4,441

SUM OF ERROR = 16,757

AVERAGE ERROR = 2,793

AVERAGE m1 = 5,684,034

$$x_6 = 2,793 / 5,684,034 = .000491$$

ml2: non-industrial wage earners

$$ml2^{t+1} = x_1 ml2^t + x_2 m3^t + x_3 m4^t + x_4 m5^t + x_5 m6^t + x_6 m7^t + x_7 ml^t$$

Assume  $x_1 = .9$ ,  $x_2 = .01$ ,  $x_3 = .1$ ,  $x_4 = .133$ ,  $x_5 = .1$ , and  $x_6 = .067$ .

<u>t+1</u>	<u>ml2<sup>t+1</sup></u>	<u>x<sub>1</sub>ml2<sup>t</sup></u>	<u>x<sub>2</sub>m3<sup>t</sup></u>	<u>x<sub>3</sub>m4<sup>t</sup></u>	<u>x<sub>4</sub>m5<sup>t</sup></u>	<u>x<sub>5</sub>m6<sup>t</sup></u>	<u>x<sub>6</sub>m7<sup>t</sup></u>	<u>Error</u>
1965	84,460	73,800	111	229	913	2,862	347	6,198
1966	80,994	76,014	138	248	1,004	3,741	435	5,414
1967	89,604	78,295	148	288	698	3,688	530	5,957
1968	92,922	80,644	185	343	457	1,591	629	6,073
1969	95,060	83,630	203	583	278	4,413	751	5,202
1970	97,912	85,554	307	691	289	4,493	832	5,746

SUM OF ERROR = 34,590

AVERAGE ERROR = 5,705

AVERAGE ml = 5,084,034

$$x_7 = 5,765/5,684,034 = .001014$$

ml3: self-employed non-agricultural

$ml3^{t+1} = x_1 ml3^t + x_2 m3^t + x_3 m3^t + x_2 ml^t$  is the assumed relationship. .9 is picked for  $x_1$ ,  $x_2$  is assumed. .01,  $x_3$  is derived.

<u>t+1</u>	<u>ml3<sup>t+1</sup></u>	<u>x<sub>1</sub>ml3<sup>t</sup></u>	<u>Error</u>
1965	10,300	9,000	1,300
1966	10,609	9,270	1,339
1967	10,927	9,548	1,379
1968	11,255	9,834	1,421
1969	11,593	10,130	1,463
1970	11,941	10,434	1,507

SUM OF ERROR = 8,409

AVERAGE ERROR = 1,401

AVERAGE ml = 5,684,034

$$x_2 = 1,401/5,684,034 = .000246$$

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m14: self-employed agricultural

$m14^{t+1} = x_1 m14^t + x_2 m2^t + x_3 m1^t$  is the assumed relationship.

.9 and .1 are picked for  $x_1$  and  $x_2$ .  $x_3$  is derived.

<u>t+1</u>	<u>m14<sup>t+1</sup></u>	<u>x<sub>1</sub>m14<sup>t</sup></u>	<u>x<sub>2</sub>m2<sup>t</sup></u>	<u>Error</u>
1965	762,200	666,000	15,678	80,522
1966	785,066	685,980	17,451	81,635
1967	808,620	706,559	19,314	82,747
1968	832,900	727,758	21,264	83,880
1969	857,900	749,610	23,472	84,818
1970	883,600	772,110	25,271	86,219

SUM OF ERROR = 499,821

AVERAGE ERROR = 83303.5

AVERAGE m1 = 5,684,034

$$x_3 = 83303.5 / 5,684,034 = .0147$$

m15: persons having moved through human resources sector.

Once people have entered this category they are of no interest to us. No records are kept.  $m15^{t+1}$  is conveniently a function of all other variables at t.

Total Transition Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Basic Data
1.022	1.022	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5,068,519
.0124	.0124	.75	0	0	0	0	0	0	0	0	0	0	0	0	0	383,644
0	0	.075	.5	0	0	0	0	0	0	0	0	0	0	0	0	43,455
0	0	0	.1375	.5	0	0	0	0	0	0	0	0	0	0	0	8,917
0	0	0	.1249	0	.5	0	0	0	0	0	0	0	0	0	0	9,631
.0037	.0037	0	.1	0	0	.5	0	0	0	0	0	0	0	0	0	50,521
0	0	0	0	.1	0	.1479	.7	0	0	0	0	0	0	0	0	14,604
.000214	.000214	0	.01	0	0	0	0	.9	0	0	0	0	0	0	0	11,940
.000159	.000159	0	.01	0	0	0	0	0	.9	0	0	0	0	0	0	9,552
.00116	.00116	0	0	.1	.133	.1	.067	0	0	.9	0	0	0	0	0	107,465
.000491	.000491	0	0	.1	.133	.1	.067	0	0	0	.9	0	0	0	0	71,640
.001014	.001014	0	.01	.1	.133	.1	.067	0	0	0	0	.9	0	0	0	97,912
.000246	.000246	0	.01	0	0	0	0	0	0	0	0	0	.9	0	0	11,941
.0147	.0147	.1	0	0	0	0	0	0	0	0	0	0	0	.9	0	883,600
0	0	.09	.1	.1	.1	.115	.1	.1	.1	.1	.1	.1	.1	.1	0	0

COMMENTS - Part IV

Some interesting problems surface in developing the flow model of Saudi human resources. We know exactly where we would like to have better information. In general, we would like to have primary data strings for each of our categories. As the model currently stands, these strings are derived from work force estimates and percentages that are ten years out of date. Secondly, we would like to know where people in Saudi Arabia typically move with respect to our categories. It is one thing to claim "Saudi's don't move from labor positions back to teacher training" and quite another to know that this is the case. The transition matrix, although fitting data strings, is user constructed and could have been done entirely differently with equal data matching performance.

The questions we would really like to get at, or perhaps the ones that the Saudi's would like to get at, are untouched by our analysis. Specifically, we are interested in the behavior of the transition matrix over time. How do the transition constants change? Are they controllable in the technical sense of being functions of variables that are purposively manipulable or at least potentially purposively manipulable by the Saudi government? These questions are assumed out of existence by the constant nature of our transition matrix. Rather than being an interesting control throttle for our decision stratum, human resources becomes as much an external constraint as length of daylight and temperature.

One advantage of the current formulation of human resources is that it can be easily re-estimated. Another is that should someone invent a process which generates transition constants it could be programmed as a sub-routine without necessitating a redesign of the human resources module.



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